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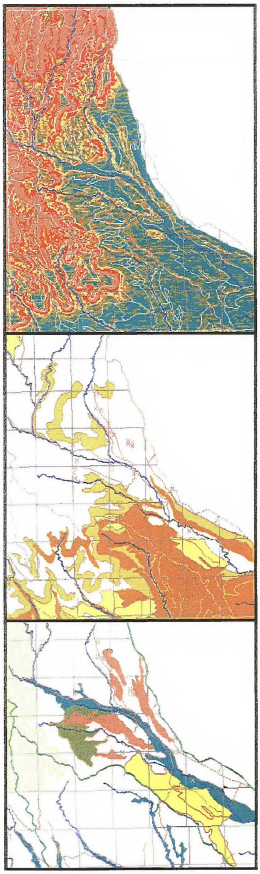
Watershed Soil Erosion, Runoff and Sediment Yield Prediction Using Geographic Information Systems:

A *Manual of* GIS *Procedures*



by

Jacek Blaszczynski
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Introduction

Why Model with GIS?

Soil erosion, including detachment and transport, is a natural phenomenon; its rates depend on climate, terrain morphology, soil type, vegetative cover, and the kinetic energy of wind and water. Human activities which disturb the land surface, particularly vegetative cover, can cause an increase in soil erosion rates. This can lead to loss of soil productivity due to reduction of the thickness of topsoil and removal of nutrients. Soil erosion also causes siltation of streams and rivers, as well as pollution with compounds resident in soils, such as nutrients, pesticides, salt, and toxic wastes. Soils can be washed into estuaries and coastal ocean waters, also causing pollution and destruction of marshes, oyster beds, and fisheries. Finally, in arid and semi-arid climates, an increase in soil erosion has been linked to desertification.

The ability to evaluate the locations and rates of soil detachment and sediment yield caused by kinetic energy of rainfall is essential to decisionmaking for ecologically sound management of natural resources. Locations of critical erosion areas have to be known when planning the placement of man-made structures or designating areas for recreation, if these have an effect of disturbing the land surface. Knowledge of locations and rates of erosion and transport is also needed to design and implement appropriate soil conservation practices, such as revegetation, contour plowing and pitting, and building of erosion control structures.

Since the processes related to water soil erosion are diffuse, occur at varying rates over the landscape, and are dependent on a variety of factors that change continuously, a direct measurement of soil erosion is impractical. Researchers therefore have turned to using prediction models to inventory erosion for local and regional assessments (Foster, 1988; USDA, 1981). The primary models used currently for this purpose are the Universal Soil Loss Equation (Wischmeier and Smith, 1978; Allen,

1981; Foster, 1988) and the Revised Universal Soil Loss Equation (Renard et al., 1990) to predict average yearly sheet and rill erosion, and the Modified Universal Soil Loss Equation (Allen, 1981; Johnson et al., 1986; Jackson et al., 1986; Foster, 1988) for prediction of sediment yield from individual storm events using the SCS Curve Number method for runoff hydrograph development (McCuen, 1984; Moore, 1988). Other models, such as the Watershed Erosion Prediction Project (Nearing et al., 1990) are currently being developed. However, the USLE type of soil prediction technology continues to be the most utilized approach to evaluating soil erosion.

A Geographic Information System (GIS) provides the means to quickly analyze and geographically model distributed data related to various environmental criteria used in making estimates of the quantities of soil erosion, runoff, and sediment yield. The GIS permits utilization of data from sources such as remote sensing imagery, digital maps, and textual/tabular information collected in the field. The georeferenced data can then be modeled using GIS spatial analysis functions to provide maps and tabular reports needed for decisionmaking. The information provided by GIS processing includes the evaluation of existing conditions and the effects of various management alternatives to provide guidelines for the selection of an appropriate management approach to preventing soil erosion.

About This Manual

This manual describes methodologies developed for interfacing the Revised Universal Soil Loss Equation (RUSLE), the Soil Conservation Curve Number (SCSCN) method, and the Modified Universal Soil Loss Equation (MUSLE) with Geographic Information Systems to quickly and effectively estimate the potential sheet and rill erosion, runoff, and sediment yield for large areas. It is necessary to apply the methodologies described here as a cooperative effort between a GIS applications specialist and a resource specialist well acquainted with the area being modeled. A variety of decisions must be made which depend on field experience in the area being modeled and knowledge of the various capabilities of BLM's Map Overlay and Statistical System (MOSS) and the Map

Analysis Processing System (MAPS), the Hydrologic Terrain Analysis Software (HTAS), and the cartographic modeling process. Some of the questions that need to be answered when using one of the soil loss equations are:

- What is the best way to determine values for the factors of the Revised Universal Soil Loss Equation and the Modified Universal Soil Loss Equation?
- Would it be more appropriate to use the traditional Universal Soil Loss Equation rather than the Revised version for the area under study?
- How should the erosion control practice (P) factors be estimated, since the RUSLE method provides only a limited number of options?
- Should the factors be tied to the individual soil or vegetation polygons or to soil and vegetation types that might consist of several polygons?
- How could existing soil and vegetation maps be enhanced to more closely reflect the reality of soil types and vegetation cover distribution?
- How should the slope lengths map obtained through automated procedures be edited to reflect the reality of the field more accurately?
- What kind of products should be developed to help management make accurate decisions?

This first version of the manual is intended to provide general discussion of some of these issues, step-by-step instructions on applying the GIS methodologies at the simplest level, and an introduction to modeling of land management scenarios. The manual is not designed to teach the use of the RUSLE and Wildcat4 programs. We hope that in the future editions of this manual we will be able to incorporate the RUSLE and Wildcat4 program capabilities directly into the GIS, so that you will not need to rely on the diskettes.

The GIS methods provided here are flexible. It is up to you to modify these methods to help you with your resource management needs. The GIS methods are currently being tested in the field, and any input you may have to improve the applications and this manual are greatly appreciated.

While all the GIS procedures discussed in this manual are described in terms of the capabilities of the MOSS/MAPS GIS and the HTAS contributed software, the author believes that these procedures are almost completely transferrable to the latest ARC/INFO 6. 1 release with an important, but workable, exception. This exception is that while, to the best of the author's knowledge, the HTAS capabilities have been incorporated into ARC GRID 6. 1 hydrologic modeling commands, the system still lacks a SLOPE LENGTH command which permits easy calculation of slope lengths for use in the RUSLE/GIS Interface. At BLM this problem can be currently remedied by the fact that we will continue to use the MOSS/MAPS system concurrently with the new ARC/INFO systems for at least a few years. Therefore, if we choose to transfer these procedures to the new systems, the slope length maps can be prepared in the MAPS GIS. In the future we hope that ESRI will incorporate some version of the SLOPE LENGTH command into their ARC/INFO GIS. The next edition of this manual will be oriented toward presentation of these methods in terms of ARC/INFO commands.

This manual consists of three main chapters, each containing three sections. The first chapter provides a general discussion of the RUSLE/GIS procedure to develop a soil erosion map, the methods for runoff hydrograph generation using GIS and Wildcat4 programs, and the GIS methods for calculating sediment yield from a storm event using MUSLE. We suggest that you read the first chapter completely and gain an overall understanding of the approach. The second chapter provides step-by-step instructions on how to apply the methods and helps you to develop actual products using your own data. The goal is to guide you through the simplest level of the process of modeling while also making you aware of the alternatives. The third chapter discusses two approaches to modeling of management alternatives: through veg-

etation improvement and creation of dams. The procedures are discussed only generally; detailed examples are not provided because this segment of the manual requires that you have read thoroughly through the previous chapters, and have become well acquainted with the capabilities of MAPS GIS and the HTAS. Therefore the third chapter is meant only for the advanced users of those systems. You will become an advanced user by running through the models presented in Chapter 1 and Chapter 2 of this manual, and through study of the HTAS manual available from your state GIS coordinator.

The application of the model is a team process involving at least both a GIS and a resource specialist, preferably a soil scientist or a hydrologist, unless the modeler has adequate background in both areas of expertise. While the GIS specialist should be knowledgeable in the use of GIS and HTAS, as well as the principles of cartographic modeling, the Resource specialist should be acquainted with the RUSLE, MUSLE, and Wildcat4 programs available with this manual, particularly with respect to the nature of input data required by these programs and the sources of the data for the study area. Each of the steps of the modeling process should be discussed thoroughly to develop a good understanding of what is being done. Without that understanding, it will be impossible to evaluate the validity of the results. At a minimum, use of GIS models for resource analysis and management requires:

- understanding the limitations of the model and the precision and accuracy of the input data,
- being aware of the types of transformations the data undergo while processed by various GIS algorithms and the effects of processing on the precision and accuracy of the data, and
- knowing the methods of presenting the products to provide meaningful guidelines for management decisionmaking.

The scope of this manual does not include a detailed discussion of how to approach these issues. Since the resolution of these issues is strongly dependent on the

nature and expectations of each project, it is left to your creativity and scientific know-how to determine the best approach. Learning to model using GIS opens many vistas and is very much a process of discovery both about the natural processes being modeled and the means of analyzing and presenting the information.

GIS provides tremendous power to help visualize and understand resources and impacts of management. Have fun!

Chapter 1
General Description of GIS-Based Soil Erosion Prediction, Runoff Modeling, and Sediment Yield Prediction Procedures

A. Soil Erosion Prediction with GIS using the Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) is based on the Universal Soil Loss Equation (USLE) with changes made to accommodate the environmental conditions on arid and semi-arid rangelands of western United States. The RUSLE factors represent various environmental parameters which influence sheet and rill erosion, including rainfall (R), soil erodibility (K), slope gradient (S), slope length (L), surface cover (C), and erosion control practice (P). The RUSLE/GIS application reflects the basic USLE structure (Wischmeier and Smith, 1978), as follows:

$$A = R * K * L * S * C * P$$

A *is the average yearly sheet and rill soil loss potential in tons per acre per year;*

R *is the rainfall and runoff factor in number of rainfall erosion index units;*

K *is the soil erodibility factor, which is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, and defined as a 72.6-ft length of uniform 9-percent slope continuously in clean tilled fallow;*

L *is the slope-length factor, which is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions;*

S *is the slope-steepness factor, which is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions;*

C *is the cover and management factor, which is the ratio of soil loss from an area with specified cover and management to that from an identical tilled continuously fallow area; and*

P *is the support practice factor, which is the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down the slope.*

In the RUSLE/GIS application, all the factors except for rainfall are tied to maps. When you overlay these maps, the resultant map produces the soil erosion potential map. To run the application, you need digitized vector polygon maps of soil types and vegetation cover types, and a Digital Elevation Model (DEM) for the area of study. In addition, to access to MOSS/MAPS and the appropriate data, you need the DOS-compatible version of the RUSLE program which is included with this manual.

The application of the RUSLE/GIS Interface includes following steps:

1. Prepare the cartographic data so that all maps are in the same projection (MOSS commands used: DESCRIBE, PROJECTION).

2. RASTERIZE vector maps so they are compatible with each other in terms of cell size and the number of rows and columns. This usually involves normalizing your rasterized vector maps to the DEM (MAPS commands used: RASTERIZE, DESCRIBE, CUT).

3. Determine the value of the rainfall (R) from 2yr-6hr precipitation data for the area of study using the PC RUSLE program.

4. Develop a list of subjects and subject values for each rasterized vector map, that is, the cell soil type

NOTE:
Vector maps can be rasterized by SUBJECT, which represents a particular type, e.g., soil or vegetation coverages, that consists of several polygons or items; or by ITEM, which represents a single unbroken area or polygon that belongs to a particular type.

map and the cell vegetation type map (MAPS command used: DESCRIBE).

5. Determine the values for the soil erodibility (K), the vegetation cover (C), and the erosion control practice (P). These values can be obtained from soil surveys, or by running the DOS PC RUSLE program and providing appropriate information. In most cases, P factor values need to be known only when developing maps or tables showing impacts of various management alternatives.

6. Assign each of the factor values to the appropriate subject (soil or vegetation type) of each raster map, creating a factor map; for example, a K-factor map from a soil type map or a C-factor map from a vegetation cover type map (MAPS command used: RENUMBER).

7. Develop a slope map from the DEM for the study area (MAPS commands used: SLOPE, options AVERAGE or SUM).

8. Develop a slope length map from the DEM (MAPS commands used: SLOPE option LENGTH).

9. Edit the slope length map to more closely reflect field estimates of slope lengths (MAPS command used: RENUMBER).

10. Develop a terrain (LS) factor map by combining the slope and slope lengths maps using the equation for the LS factor (MAPS command used: MATH).

11. Develop a sheet and rill soil erosion potential (A) map by combining the R-factor value with the K-factor map, the LS-factor map, the C-factor map, and the P-factor map. The erosion potential map represents average yearly soil loss. A resource specialist with experience of the study area should review the map to identify gross errors. If possible, compare the maps with data collected using ero-

NOTE:
Depending on the amount of information you have and how much effort you want to put into the development of your model, you can assign K-, C-, and P-factors to specific polygons or items rather than to subjects. For example, if you know that a particular polygon belonging to soil type 73 has a different soil erodibility (K) factor than another polygon belonging to the same soil type 73, you can assign the factor value to individual polygons rather than entire soil types.
Another approach to refine the quality of your maps is to intersect a raster soil type map with a slope class map developed from a DEM, and then assign a soil erodibility (K) factor to a particular slope class within a particular unit. A very general vegetation cover map can be refined by intersecting it with an aspect class map, that is, a map developed from a DEM that identifies southern- and northern-facing aspects, and then assigning vegetation cover (C) factor values to an area with a particular aspect within a particular vegetation unit.

WARNING:
Making decisions on how to approach more complex assignments of factor values requires discussion and cooperation between a resource and GIS specialist.

NOTE:
An erosion potential map could be prepared to show the effects of each management alternative.

NOTE:

Plot the erosion potential maps for the original conditions or for each of the alternatives as a three-dimensional image or on a 3-D surface. The information contained in these maps can be summarized in terms of average or total soil erosion per a chosen unit, which could be a slope class, a soil or vegetation type, a soil or vegetation polygon, a subwatershed, or any other unit digitized and made into a raster map, such as a buffer zone of 500 feet around a stream. In that way the erosion potential map can be used as one of the components of other cartographic models.

sion gauges for approximate correlation at various locations (MAPS command used: MATH).

12. Develop various products that provide management with necessary information (Commands used: GENPLOT in MOSS; 3D, TOTAL, SCORE in MAPS; and other).

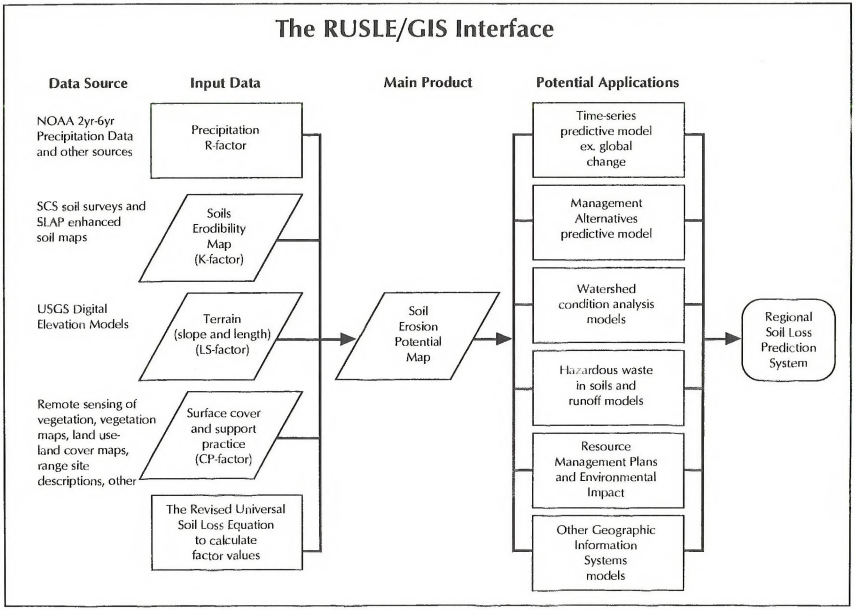

Plate 1. The basic structure of the RUSLE/GIS procedure.

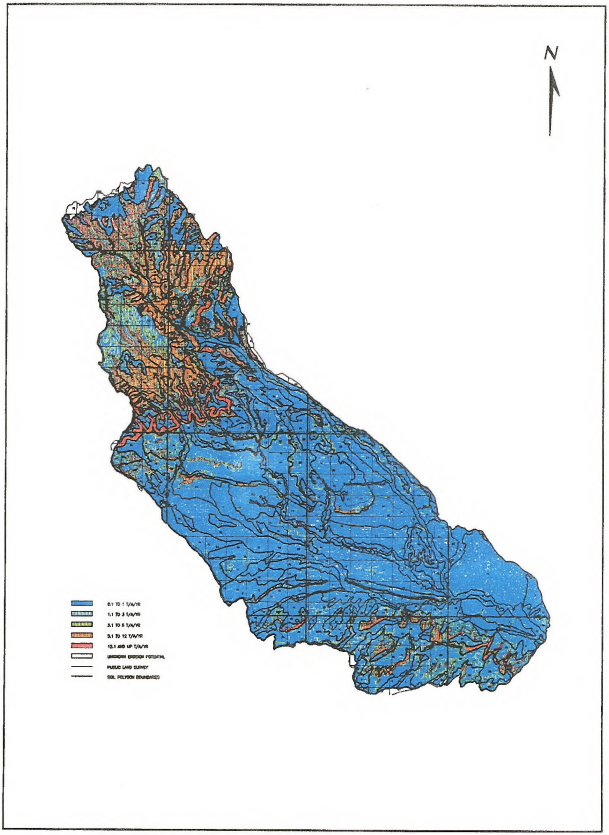

Plate 2. Sheet and rill erosion potential map for a Utah watershed prepared using the RUSLE/GIS procedure.

B. Runoff Modeling with GIS using the SCS Curve Number Method

To model sediment yield for a storm using the Modified Universal Soil Loss Equation (MUSLE), it is first necessary to determine runoff by developing a runoff hydrograph using storm and watershed characteristics data. The runoff hydrograph provides information on peak flow and volume of runoff per storm per watershed, which is important to calculation of the runoff factor in the MUSLE. In this manual, the runoff hydrograph is generated using DOS PC program Wildcat4, which is based on the SCS "Curve Number" method using triangular unit hydrographs as outlined in the SCS National Engineering Handbook, Section 4, Hydrology ("NEH-4") (Moore, 1988). This manual refers to the procedure as the Curve Number Runoff/GIS method.

As input, the program accepts data on the duration, rainfall depth, and distribution of the storm, and on watershed characteristics, including average slope, length of the longest channel, area of the hydrologic response units in the watershed, and the curve numbers associated with them. The power of the GIS lies in the ability to quickly provide these data. GIS can subdivide large areas into small subwatersheds, permitting more precise calculations based on smaller analytic units. It permits fast intersection of soil and range characteristics to identify various hydrologic response units and easy calculation of average slopes within each subwatershed. Finally, it helps in determining the lengths of the longest channels, particularly in areas where location of the channel might not be easily identified using visual methods.

To develop runoff hydrographs for watersheds in your area of study, you need the Hydrologic Terrain Analysis Software (available as contributed software with the GIS), the Wildcat4 program, a DEM, and preferably a digital stream and channel map, if one is available, for the area of study in addition to the MOSS/MAPS GIS.

The Curve Number Runoff/GIS procedure consists of the following basic steps:

1. Prepare a map of subwatersheds from the DEM within the study area using the watershed delineation programs provided with the Hydrologic Terrain Analysis Software (HTAS). The watersheds should not be more than 5 square miles in size (3,200 acres) (MAPS commands: MAPSTOIDIMS, IMPORT, HTAS).

2. Edit and label the subwatershed map so that you know where each unit is located (MAPS commands: RENUMBER, PLOT, QUERY, LABEL, DESCRIBE).

3. Generate a vector map of line segments representing the actual or potential longest stream or channel courses for each subwatershed. Label the lines with the same subject label as their subwatershed. Obtain a list of the lengths of these line segments. The longest stream lengths should not be more than 20,000 feet in length (MOSS commands: GENERATE, PLOT, WINDOW, MERGE).

4. Prepare a cell (raster) map of the soil hydrologic groups and range condition units for the area of study. Intersect these to produce a Hydrologic Response Units (HRU) map. Assign a unique curve number to each hydrologic response unit (MAPS commands: RENUMBER or EXTRACT, MATH).

5. Intersect the HRU map with the subwatershed map to obtain a map of the subwatershed hydrologic response units. Produce an area listing for each of the units of the new map (MAPS commands: INTERSECT, AREA).

6. Prepare a list of the average slopes for each of the subwatersheds (MAPS command: TOTAL).

7. Prepare a table which contains all the information you just generated. For each subwatershed, the table should include average slope, length of the longest channel, number of HRUs, area of each

HRU in square miles, and the curve number of each HRU.

8. Input this information into the Wildcat4 program, together with the storm data, to create a unique watershed file for each subwatershed and a unique storm file for each storm. Generate a runoff hydrograph for the subwatersheds for each storm. The runoff hydrograph provides you with information on the volume of runoff (Q) and peak flow (q_p), which can be used to determine the runoff factor for each subwatershed.

WARNING:

During testing it appeared that the Wildcat4 program had difficulties in processing all the watershed and storm data. Since the program is not our product, we currently cannot do anything about this problem. Since it works with most of the data, we recommend that you play around with the watershed data, making the units smaller and decreasing lengths of the longest stream channels, to obtain a combination that will work for all storms. In the meantime, if genuine interest in this modeling continues, we will try to incorporate the program's capabilities directly into the GIS for the second edition of the manual.

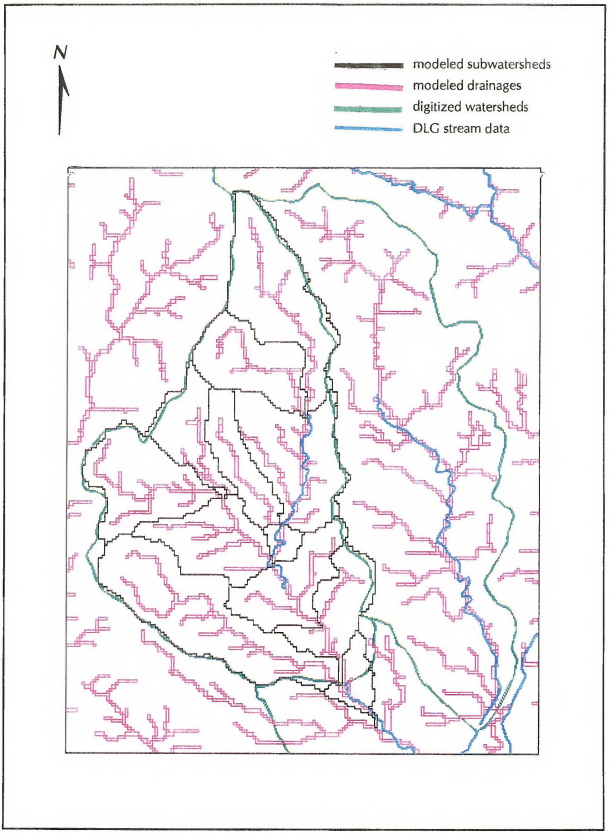

Plate 3. Map of Bootlegger subwatersheds in Utah showing GIS/HTAS analytic products used for runoff and sediment yield estimation.

C. Storm Sediment Yield Prediction with GIS using the Modified Universal Soil Loss Equation

The Modified Universal Soil Loss Equation (MUSLE) is a method used to determine watershed sediment yield per storm and generally follows the structure of the Universal Soil Loss Equation, with the exception that the USLE rainfall factor is replaced with the runoff factor. The runoff factor is calculated for each storm and subwatershed from the runoff hydrograph developed using the Wildcat4 program in the previous section. This calculated runoff provides information on peak flow and the volume of runoff. Using this information, and the other factors of the USLE, the MUSLE equation calculates sediment yield for each storm event in a watershed.

NOTE:
Because MUSLE utilizes the K, LS, C and P factor maps developed when applying the RUSLE/GIS method, you should apply the RUSLE/GIS procedure first if you want to produce both soil erosion and sediment yield maps. Otherwise, simply go through all the steps of the procedure that deal with generation of various factor maps.

The structure for the MUSLE process is as follows:

$$S = R * K * L * S * C * P$$

where $R = a(Q * q_p)^b$ *so the equation becomes:*

$$S = a(Q * q_p)^b * K * L * S * C * P$$

where

S *is the sediment yield per calculation unit (watershed) in tons;*

a *is a constant;*

b *is a constant;*

Q *is the volume of runoff in acre-feet;*

q_p *is the peak flow rate in cubic feet per second;*

K *is the soil erodibility factor, which is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, defined as a 72.6-ft length of uniform 9-percent slope continuously in clean tilled fallow;*

L *is the slope-length factor, which is the ratio of soil loss from the field slope length to that from a 72. 6-ft length under identical conditions;*

S *is the slope-steepness factor, which is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions;*

C *is the cover and management factor, which is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow; and*

P *is the support practice factor, the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down the slope.*

The constants **a** and **b** can vary depending on sources and areas of application. To be consistent for the purposes of this manual, we will utilize the constants provided in the DOS personal computer RUSLE program included with this manual in which a = 11.8 and b = .56 (the MUSLE subroutine). These constants were originally derived by Williams (1982) on the basis of individual storm data from 18 basins in Texas and Nebraska and validated on 102 basins throughout the United States. Williams (1975) indicated that it may be necessary to recalibrate the runoff term in the MUSLE to the site of interest, and this is confirmed by Johnson (1986), whose Reynolds Creek study led him to increase the exponent on the runoff term, and by Jackson, Gebhardt, and Van Haveren (1986), who believe that for long-range sediment yield estimates it will be necessary to adjust upward the exponent on the MUSLE runoff term. The GIS/MUSLE methodology permits flexible adjustment of the constant values. Because GIS decreases the size of the analytic unit, i.e., the watershed, used in MUSLE and permits the extraction of a variety of data about the landscape, it allows a more precise application of MUSLE to larger areas than has been possible until now. Comparisons of modeled sediment yields and sediment yield values obtained from flow gauges, should these be available in the area of study, can permit refinement of the constant values.

The MUSLE/GIS sediment yield prediction method consists of the following steps:

1. Follow all the steps in the Curve Number Runoff/GIS procedure to generate runoff hydrographs for each of the subwatersheds and for each storm being modeled. From this information, find the volume of runoff (Q) and peak flow (q_p) for each subwatershed during a particular storm (see Chapter 1, Section B).

2. Generate volume runoff (Q) and peak flow (q_p) maps, and relate them mathematically to produce a runoff (R) factor map for each subwatershed (MAPS commands used: RENUMBER or EXTRACT, MATH).

3. Develop the K, C, LS, and P factor maps using appropriate steps of the RUSLE/GIS soil erosion prediction procedure (see Chapter 1, Section A).

4. Relate mathematically the runoff (R) factor map to the other factor maps prepared while running the RUSLE/GIS procedure to produce the sediment yield (S) map for the area of study (MAPS commands used: SIZE, MATH).

5. Produce various products and extract information from the sediment yield map as needed for your project. Compare differences between maps for various types of storms, analyze effects of different control practices, and plan management alternatives. (Use various commands, depending on the products you require.)

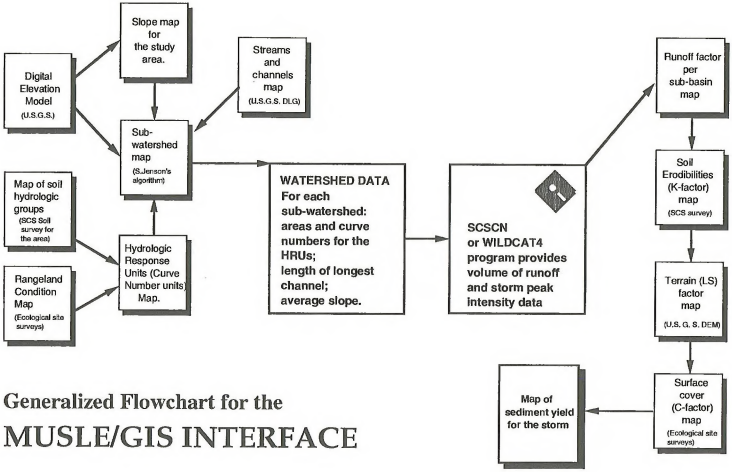

Plate 4. The basic structure of the complete MUSLE/GIS procedure.

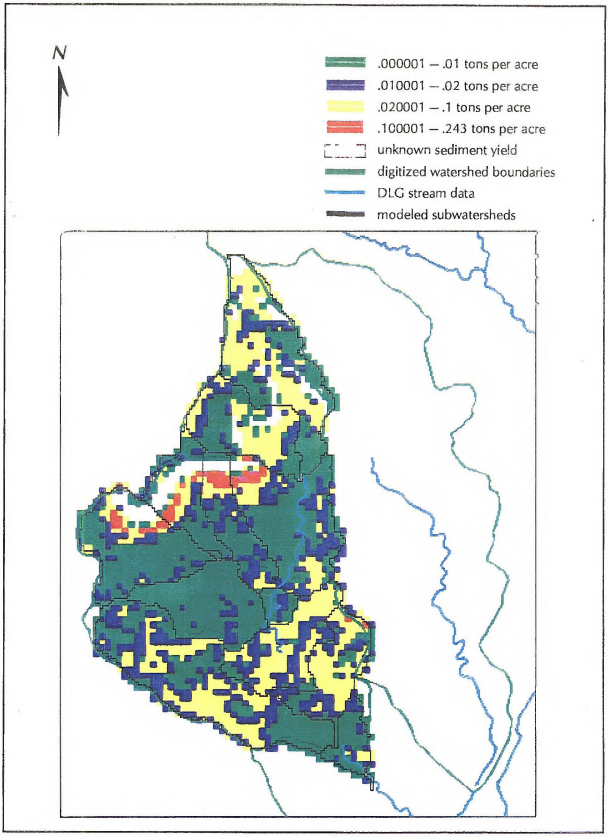

Plate 5. Sediment yield map for the August 2, 1991 storm, Bootlegger West subwatershed in Utah.

Chapter 2
Detailed Description of GIS-Based Soil Erosion Prediction, Runoff Modeling, and Sediment Yield Prediction Procedures

A. RUSLE/GIS Procedure for Predicting Sheet and Rill Soil Erosion

Step 1. Prepare maps for overlay.

The RUSLE/GIS application requires several data layers containing information about the geographic distribution of different environmental parameters. These data layers are related to each other using raster processing capabilities of the BLM's Map Analysis and Processing System (MAPS). In MAPS this is possible only if the data layers have the same projection, contain the same number of rows and columns, and cover precisely the same geographic location. Furthermore, since the data format of some of the original maps is vector, the maps must be converted into cell format for raster processing.

- Identify whether the projections of the soils map, the vegetation map, and the DEM are the same (MOSS commands used: DESCRIBE and PROJECTION).

- Reproject the vector maps to the projection of the DEM if the projections are not the same (MOSS command used: PROJECTION).

- Create a window for the polygonal maps by WINDOWing on the DEM to convert into raster (cell) maps once the maps are in the same projection (MOSS command used: WINDOW).

- Transform the vector soil and vegetation maps into type 7 discrete raster maps. Specify the same cell height and width of cells as the DEM, usually 30x30 meters (MAPS command used: RASTERIZE with SUBJECT option).

EXAMPLE:

RASTERIZE (oldmap) FOR (newmap)
BY SUBJECT TYPE 7, HEIGHT 30 WIDTH 30

- Perform a quick overlay test to ensure compatibility by adding or multiplying the maps together (MAPS command used: MATH).

EXAMPLE:

MATH (oldmap1) + (oldmap2) + (oldmap3)
FOR (newmap)

- If the maps cannot be related, the error message will tell you whether this is caused by different projections or unequal numbers of rows and columns. If the problem is different projections, check projections again using the DESCRIBE command/PROJECTION option in MAPS. Correct the problem by projecting your map again.

- If the problem is an unequal number of rows and columns, use the DESCRIBE command/HEADER option to compare the number of rows and columns in the rasterized vegetation and soil maps with the DEM. You might also want to PLOT the maps on top of each other to see how they overlap. One way to correct the problem is to use the WINDOW command to window in on the map that has the least number of rows and columns. This should establish a window containing all the maps. Use the CUT command/WINDOW option to cut the larger maps to the size compatible with the smallest map.

- Run the overlay test again using the MATH command.

The result of this process is data layers that can be overlaid using MAPS. You are now ready for the next step of the RUSLE/GIS application.

Step 2. Prepare the soil erodibility (K) factor map.

The base map for the soil erodibility data layer is the soil units map which has been transformed into the raster format. Values for soil erodibility (K) per soil type can be obtained by running the DOS RUSLE program on a PC and entering the following information about each soil type:

- percentage of silt and very fine sand in the soil,
- percentage of clay in the soil,
- percentage of organic matter in the soil, and
- soil structure and permeability code.

However, most soil surveys from which the soil units map was digitized already have tables of K-values which can be used to develop a K-factor map. To create a soil erodibility (K) factor map, follow these steps:

- Obtain a hardcopy of the subject table for the raster soil units map you prepared using RASTERIZE. This provides you with a list of the soil types and their cell values in the raster map. You can obtain the subject table by using the DESCRIBE command/SUBJECT option in MAPS. Capture the subject table in a COMO file and send it to the printer, or print the subject table directly from the screen.
- Find a corresponding K factor value in the soil survey for the study area for each of the subjects. Note the value next to the corresponding soil type in the subject table.
- If K values are not available from a soil survey, use the DOS RUSLE program to calculate the K factor value based on percentage of silt and very fine sand in the soil, percentage of clay in the soil,

NOTE:
In the vector soil map each of the soil types is represented by a number, which is the code for the soil. When the map is converted into raster format using the RASTERIZE command/SUBJECT option, these numbers are the source of values assigned to each particular soil type, and the values listed next to each item in the subject table correspond to the number codes for each soil type.

percentage of organic matter in the soil, and soil structure and permeability code.

- Prepare a K factor map by assigning K factor values to the subject values in the raster soil map using the RENUMBER command in MAPS. Use the list of subjects and the associated K factor values to first prepare a handwritten version of the content of the command, and then check it for errors before typing it on the screen. The RENUMBER command permits you to assign soil erodibility (K) values to as many as 64 different soil types.

EXAMPLE:

RENUMBER (soilmap)
ASSIGNING . 34 TO 746 ,
AS . 32 TO 735 AS . 28 TO 740
FOR (K-factor map)

- Type in and run the command as you wrote it out. The result is a map of soil erodibility for the study area.

- Use the DESCRIBE command SUBJECT option to produce a subject table for the soils erodibility (K) factor map you have just created. If you find problems, run the procedure again until all the errors have been corrected.

WARNING:
Make sure you check the assignments you have made before running the command and creating a K-factor map. If you provide the wrong K value for a particular soil type, your soil erosion potential map will not be accurate and you might have difficulties finding the source of error later in the process.

NOTE:
Generally the source of soil maps is the soil surveys for the area produced by the USDA Soil Conservation Service in association with other agencies. Occasionally you will find more than one K value for a single soil type represented on the map. To deal with this situation, select the K-factor value for the most predominant soil type, calculate a weighted average, or try to refine the soils map by intersecting it with a slope class map, since certain soils are generally related to a particular slope class. There is still no established soil survey enhancement methodology, although one that utilizes combined remote sensing and GIS methods is being researched at the Service Center as the Soil Landscape Analysis Project (SLAP) (Amen and Foster, 1987). Whichever method you select or devise, make sure that it is applied consistently throughout the area of study, and keep records of your approach for future reference.

Step 3. Prepare the surface cover (C) factor map.

The base map for the surface cover (C) factor data layer is a vegetation or surface cover types map which has been converted into raster format. Values for surface cover factor (C) per soil type can be obtained by running the DOS RUSLE program on a PC and entering following information for each of the vegetation types:

- percent and average height of vegetation cover,

- root mass in the top 4 inches of soil,

- percent of rock, gravel, litter and vegetation on the ground surface, and

- surface roughness number from a table provided in the program.

The steps for developing a surface cover (C) factor map are as follows:

- Obtain a hardcopy of the subject table for the raster surface cover types map you are using. The subject table contains a list of each of the vegetation types on the map. Use subject descriptions for each of the vegetation types as a reference to assign surface cover (C) factor values to each of the types. The subject table can be obtained by using the DESCRIBE command/SUBJECT option in MAPS. You can also capture the subject table in a COMO file and send it to the printer, or print the subject table directly from the screen.

- Use the PC RUSLE program to calculate the C factor values for each of the vegetation units. To do so, you need to know the percent and average height of vegetation cover; the root mass in the top 4 inches of soil; the percent of rock, gravel, litter, and vegetation on the ground surface; and a value for the surface roughness number you select from a table. Prepare a table containing these data.

- Calculate the C factor value for each of the vegetation types and note that value next to the type on your subject table.

- Assign C factor values to the subject values in the raster soil map by using the RENUMBER command in MAPS to prepare a C factor map. Use the list of subjects and the associated C factor values to prepare a written version of the command, and check it for errors before typing it on the screen. The RENUMBER command permits you to assign surface cover (C) values to as many as 64 different soil types.

NOTE:
Generally the sources of vegetation maps are classified satellite images, e. g. Landsat Thematic Mapper Data, aerial photographs, or field surveys. The precision and accuracy of these maps differ widely, so this has to be taken into account when evaluating the accuracy of the final product. Occasionally the vegetation maps can be enhanced, for example by identifying northern- and southern-facing aspects of the slopes. Since soil surveys often have good descriptions of the vegetation cover on the soil units, the soil map can also be used as a basemap for the surface cover (C) factor map. In all cases, the knowledge and experience of the resource specialist for evaluating the quality of the data, and identifying means to enhance it, form an essential component of the modeling process.

WARNING:
Make sure that you check the assignments you have made before running the command and creating a C factor map. If you provide the wrong C value for a particular vegetation type, the soil erosion potential map will not be accurate and you might have difficulties finding the error beyond this point in the process. The C factor map looks the same as the rasterized vegetation types map, except that the values for each of the subjects (vegetation types) are now values for surface cover (C) factor assigned to each type.

EXAMPLE:

RENUMBER (veg-map)
ASSIGNING .14 TO 746 ,
AS .02 TO 735 AS .28 TO 740
FOR (C-factor map)

- Produce a subject table for the surface cover (C) factor map you have just created, using the DESCRIBE command/SUBJECT option. If you find problems, run the procedure again until all errors are corrected.

Step 4. Prepare the terrain (LS) factor map.

The terrain factor map is prepared by utilizing the SLOPE and MATH command in MAPS. Since the process consists of a number of steps, prepare a CPL that accomplishes the task. The first part of the procedure is to prepare a slope gradient and a slope length map from the DEM for the study area. Then use the MATH command to combine the slope gradient and slope length maps according to the equations specified in the RUSLE program. The equations are as follows:

To obtain the slope gradient (S) factor:

IF PERSL < 8 THEN SFACT = 10 * S + .027

IF PERSL >= 8 THEN SFACT = 17.2 * S - .55

where

SFACT is the slope gradient (S) factor

To obtain the slope length (L) factor:

$$LFACT = (LENGTH / 72.6)^M$$

where:

LFACT is the slope length (L) factor and LENGTH is the actual slope length in feet

and where:

M = B / (1 + B)

B = .5 * ((S / 8.959999E-02) / (2.96 * (S .79) + .56))

S = SIN(ATN(Q))

Q = PERSL / 100 where PERSL is the slope gradient in percent

To obtain the terrain (LS) factor:

LSFACT = LFACT * SFACT

The steps of the procedure to prepare a slope gradient (S) factor map from the slope gradient map are as follows:

- Prepare a slope gradient map by processing the DEM with the SLOPE command. Since you have several options available in the SLOPE command, it is important to use one option consistently if you are trying to compare results from different areas.

EXAMPLE:

SLOPE (DEM-map)
MAXIMUM MATRIX 3 FOR (slopemap)

- Produce a map of slope gradients that are less than 8 percent by using the RENUMBER command.

EXAMPLE:

RENUMBER (slopemap)
ASSIGNING 0 TO 8 THROUGH 800 ,
FOR (slopes1th7)

- Produce a map of slopes between 8 and 50 percent using the RENUMBER command.

NOTE
The terrain factor map is only accurate for slopes less than 50 percent because of restrictions of the RUSLE.

NOTE:
By assigning zero values to cells which you do not want included in processing, you generally will obtain an outcome of zero from a MATH statement with some minor exceptions (addition and subtraction), and these cells will appear as zeros in the product. A value of 800 as the upper limit is an arbitrary number, and that number should always be greater than the highest slope percentage in the map.

EXAMPLE:

RENUMBER (slopemap)
ASSIGNING 0 TO 1 THROUGH 7.999 ,
ASSIGNING 0 TO 51 THROUGH 800
FOR (slopes8th50)

- Produce an S-factor map for slopes of less than 8 percent using the MATH command.

EXAMPLE:

MATH (SIN (ATAN ((slopes1th7) / 100)) ,
** 10) + 0.027 FOR (sfact1th7)*

- Produce an S-factor map for slopes between 8 and 50 percent using the MATH command.

EXAMPLE:

MATH (SIN (ATAN ((slopes8th50) / 100)) ,
** 17.2) - 0. 55 FOR (sfact8th50)*

- Produce an S-factor map for slopes from 1 through 50 percent using the math command.

EXAMPLE:

MATH (sfact1th7) + (sfact8th50)
FOR (sfactor)

The steps used to prepare a slope length (L) factor map from the slope length map are as follows:

- Prepare a slope length map by running the SLOPE command/LENGTH option of the DEM. The option processes the DEM by finding the steepest path uphill from each cell of a DEM to the top of a local ridge or hill, and then calculates the length of that path. That length is the value for slope length. In other words, the slope length is considered to be the overland distance from each cell of a map to the top of a local ridge or hill.

EXAMPLE:

SLOPE (DEM-map) LENGTH
FOR (lengthmap)

- Convert the units of the slope length map from meters to feet using the MATH command.

EXAMPLE:

*MATH (lengthmap) * 3.285*
FOR (lengthmap)

- Produce an S-variable map from the slope map using the MATH command.

EXAMPLE:

MATH (SIN (ATAN ((slopemap) / 100))
FOR (Svarmap)

- Produce a B-variable map from the S-variable map using the MATH command.

EXAMPLE:

*MATH ((Svarmap) / 0. 0895999) * 0.5) / ,*
*(2.96 * ((Svarmap) ** 0.79) + 0.56)*
FOR (Bvarmap)

- Produce an M-exponent map for slope length calculations.

EXAMPLE:

MATH (Bvarmap) / (1 + (Bvarmap))
FOR (Mexpmap)

- Produce an L-factor map using the MATH command.

EXAMPLE:

*MATH ((lengthmap) / 72.6) ** (Mexpmap)*
FOR (Lfactor)

- Prepare a total terrain contribution or an LS-factor map using the MATH command:

EXAMPLE:

*MATH (Sfactor) * (Lfactor) FOR (LS-factor map)*

At this point you have a terrain factor map which combines information about slope gradient and slope length for the area according to an empirically derived equation specified by the RUSLE.

Step 5. *Prepare the support practice* (P) *factor map.*

The support practice (P) factor is used in areas where erosion control practices such as contouring or terracing have been applied to rangeland. The base map for the support practice factor map can be a vegetation map, a soils map, or a map showing erosion control practice areas that has been digitized specially for use with this methodology. Values for the P factors can be obtained from a table in the DOS RUSLE program or other sources. The procedure for creating a P-factor map is the same as with the K- or C-factor maps.

Step 6. *Calculate the rainfall* (R) *factor value for the area of study.*

The rainfall (R) factor value is calculated for the entire quadrangle using the RUSLE program. Two sets of inputs are required: the location of the center of the quadrangle in degrees latitude and longitude, and the 2 year-6 hour precipitation, which can be obtained from maps in the National Oceanic and Atmospheric Administration's National Weather Service Atlas or other sources. As a further refinement of the RUSLE/GIS methodology, we plan to look into methods for showing spatial distribution of the values of the R-factor; however, these methods have not yet been developed.

Step 7. Produce the soil erosion potential map.

The soil erosion potential map is produced by multiplying the factor maps and the rainfall (R) factor value together.

EXAMPLE:

*MATH (K-factor map) * (C-factor map) * (LS-factor map) ,*
** (P-factor map) * R-value FOR (erosion map)*

The soil erosion potential map contains soil erosion values calculated for each cell in units of tons per acre per year. The soil erosion potential map is a continuous raster (type 8) map which can be combined with other raster maps for a variety of cartographic models. The accuracy of the final product is primarily dependent on the accuracy of the entered data. The map should be understood as a general, reconnaissance-level evaluation of the erosion potential of an area in terms of the combined influence of terrain, soil erodibility, vegetation cover, and rainfall on soil loss as processed by the USLE type of formula. Combining the RUSLE with GIS provides several important benefits for resource planning and management with respect to soils.

The RUSLE/GIS application:

- Permits regional scale studies by quickly processing large amounts of information from easily obtainable data sources.
- Permits modeling of various management alternatives and changing environmental conditions in space and time.
- Permits comparison of different geographic areas through application of standardized methodology which allows development of a comparative erosion index.
- Provides maps of various resolutions, depending on the resolution of the data.

- Provides a component for other GIS resource models.
- Can serve as the core methodology for further applications such as analysis of watershed condition, sediment loading of streams and rivers, and the effects of hazardous wastes in soils on water quality.

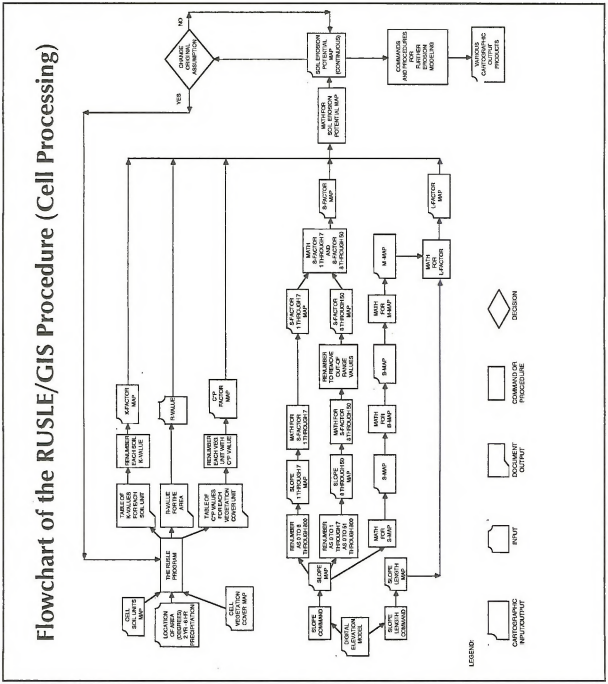

Plate 6. Detailed flowchart of the RUSLE/GIS procedure.

B. Steps of Runoff Modeling with GIS using the SCS Curve Number Method

Step 1. Prepare a subwatershed map using the Hydrologic Terrain Analysis Software (HTAS).

To prepare a map of subwatersheds, which are generally less than 5 square miles (3,200 acres) in size, from DEMs for the area of study, you need to use the Hydrologic Terrain Analysis Software (HTAS) which is available to you as contributed software under IS>CONTRIB>HTAS. The software permits analysis of the characteristics of surface morphology to derive drainage patterns and watersheds through a variety of means. The following section explains only one of the methods, derivation of subwatersheds through automated means. As one of the sub-products of this procedure you will also develop a map of drainage patterns which will help you identify the lengths of the longest channels in a subwatershed.

While these descriptions should suffice to use the HTAS in the context of this particular application, we recommend that you read the HTAS manual available from your GIS coordinator and become acquainted with the details of HTAS processing and the full range of its capabilities.

- Convert your elevation map (DEM) into the raster transfer sequential access format (IDIMS format) using the MAPSTOIDIMS command in PRIMOS. The command accepts only 1,2,4,8 and 16-bit maps. Go into MAPS, type DEBUG, and then DESCRIBE the header of your elevation maps. This should tell you if your map is more that 16 bits. You can get a 32-bit MAPS map if you have used commands like MATH on it. To get it back down to 16 bits, use the FUNCTION command/INTEGER option, and then use MAPSTOIDIMS. MAPSTOIDIMS produces two files: (elevation filename).16 (map file) and (elevation filename).TH (log file).

EXAMPLE:

(In MAPS)
FUNCTION (elevation map) INTEGER
FOR (16 bit elevation map)
(At the PRIMOS level)
OK, **MAPSTOIDIMS**
MAPS TO IDIMS CONVERSION
Enter macro file name to execute file copy
(Default is TMCOPY)
<CARRIAGE RETURN>
Enter tape drive name MT0 or MT1
(Default = MT0)
<CARRIAGE RETURN>
Enter tape drive density
(800, 1600 or 6250; Default = 1600)
<CARRIAGE RETURN>
How many maps are already on this tape ?
<CARRIAGE RETURN>
Please enter the DIRECTORY
(under MOSSDATA) or WORK
and the . DT (project master or
POLYGON : i. e. , WOLSAG WOLSAG.
DT or WORK POLYGON. DT
: **WORK POLYGON. DT**
Enter map name (CR = End)
: **DEM.MAP** (16 bit elevation file)
Map - DEM.MAP has been processed.
Enter map name (CR = End)
:**<CARRIAGE RETURN>**
* INSTRUCTIONS TO COMPLETE
MAPSTOIDIMS *

1) List out the .TH file created in the same directory that the MAPSTOIDIMS was executed (SPOOL or SLIST on the PRIME). This file contains the MBR, cell size, and projection criteria of the file, and needs to accompany the TAPE transfered to IDIMS

2) Run the macro called TMCOPY to transfer the cell file to magnetic tape:

Mount the tape

```
Run TMCOPY (CPL TMCOPY)

MAPSTOIDIMS completed.

**** STOP
```

The program produces a raster transfer format map called DEM.MAP.16 and a log file called DEM.MAP.TH.

- Copy the map to the directory where you are storing your Watershed Delineation Programs, or create a way to access these programs directly from your directory. You first need to convert your raster transfer sequential access format elevation map to the direct access format that the programs use. Use the CONVERT program in the IS>CONTRIB>HTAS directory. To run convert, you need to know the number of rows (lines) and columns (samples) in your map.

EXAMPLE:

```
OK, R IS>CONTRIB>CONVERT
Conversion desired
        (0=I*2 transfer-to-direct, 1=I*2 or
        I*4 direct-to-transfer):
        0
Transfer DEM input image name:
        DEM.MAP.16
Direct access output DEM image:
        DEM.LEV
Lines in image:
        1334
Samples in image:
        1279

Converted        200 lines
Converted        400 lines
Converted        600 lines
Converted        800 lines
Converted       1000 lines
Converted       1200 lines

**** STOP
```

- Develop a map which has all depressions in the elevation map filled. This is needed to route water flow through depressions in the topography of the area. Use CONCAVE and provide the number of rows (LINES), number of columns (SAMPLES), and the size of the overlap (OVERLAP) used to fill the depressions (one number for both the rows and columns since the overlap is square). The overlap should be larger than the largest depression you expect. Then provide the name of the direct access format elevation map in single quotes and the name of the system you are using, here PRIME in single quotes. The program rewrites the original elevation file and **does not create a new file**.

EXAMPLE:

```
OK, R IS>CONTRIB>CONCAVE

ENTER NL,NS,BOXNL,BOXNS,OVERLAP,LEV
FILE,SYSTEM(UNIX,VMS,PRIME)
1334,1279,200,200,100,'DEM.LEV','PRIME'

System = PRIME
Open as a Prime direct access file, ns = 1279
        DEM.LEV

opened successfully
SL =     1
SL =   101
SL =   201
SL =   301
SL =   401
SL =   501
SL =   601
SL =   701
SL =   801
SL =   901
SL =  1001
SL =  1101
SL =  1201
SL =  1301

**** STOP
```

- Prepare the flow direction map using the DIRECT command. Input the following data: number of rows (lines), number of columns (samples), a value of 0 (assuming this is not a restart after the program was stopped in the middle of processing the map, otherwise 1 for a restart), name of the elevation file with filled depressions (product of CONCAVE and the same name as the original direct elevation file) in single quotes, name of the new flow direction file in single quotes, and system name PRIME in single quotes.

EXAMPLE:

```
OK, R IS>CONTRIB>DIRECT

ENTER NL,NS,CODE 1 TO RESTART,LEV FILE,DIR
FILE, SYSTEM(U NIX,VMS,PRIME)
1334,1279,0,'DEM.LEV','DIR.MAP','PRIME'

Open ELEV and DIR files, ns = 1279
        DEM.LEV

opened successfully

        DIR.MAP

opened successfully

DOWNWARD PASS      1FIRSTL
2LASTL               1333
UPWARD PASS        2FIRSTL
33LASTL              1312
DOWNWARD PASS      3FIRSTL
133LASTL             1218
UPWARD PASS        4FIRSTL
655LASTL             1154
DOWNWARD PASS      5FIRSTL
808LASTL             1115

**** STOP
```

- Prepare a flow accumulation map using the COUNT program. The program calculates how many other cells are flowing into a particular cell;

the value in each cell of the COUNT.MAP is that number. Input the number of rows (lines), number of columns (samples), a value of 0 if this is not a restart, the "flow direction" filename in single quotes, the new "count" filename in single quotes, and the system name PRIME in single quotes. This program creates a new file, the "count" file.

EXAMPLE:

```
OK, R IS>CONTRIB>COUNT

ENTER NL,NS,CODE 1 TO RESTART,
DIR FILE,COUNT

FILE,SYSTEM(UNIX,VMS,PRIME)
1334,1279,0,'DIR.MAP','COUNT.MAP','PRIME'

DOWNWARD PASS   1

UPWARD PASS   2

DOWNWARD PASS   3
.
.
.
UPWARD PASS   66
DOWNWARD PASS   67
UPWARD PASS   68

**** STOP
```

- Use the DELTA program to create a "delta" file. The inputs to this program are the number of rows (lines), the number of columns (samples), the "flow direction" filename in single quotes, the "count" filename in single quotes, the "delta" filename in single quotes, and the system name PRIME in single quotes. This program creates a new file, the "delta" file.

NOTE:
You can import the "count map" using a newer version of the IMPORT command released in 1993 under the IS>CONTRIB>HTAS contributed software directory. This new version permits importation of a 32-bit or a double-word map into MAPS, and the "count map" is the only map produced by the HTAS which is in 32-bit format. Once imported, the shading, plotting, or extraction of ranges of values produces a drainage network pattern which can be used to identify areas of potential or existing channels based on the shape of the terrain.

EXAMPLE:

OK, **R IS>CONTRIB>HTAS>DELTA**

ENTER NL,NS,DIR FILE,COUNT FILE,DELTA FILE,SYSTEM(UNIX,VMS,PRIME)

1334,1279,'DIR.MAP','COUNT.MAP', 'DELTA.MAP','PRIME'

**** STOP

The "DELTA" command creates a map of "delta" values. The "Delta" value is the amount of increase in flow accumulation value in the direction of flow. "Delta" values are computed for every cell by subtracting the flow accumulation value of a cell from the flow accumulation value of the cell into which it flows. Imagine that two cells with a flow accumulation value of 1,000 flow into a single cell with a flow accumulation value of 2,000. The "delta" value of each of these cells will be 1,000. Since they both flow into the same cell, they form a junction of potential streams or channels. In an area where there is no juncture of tributaries along the stream channel, the "delta" value or the flow accumulation increment will always be 1, because flow proceeds from one cell to another cell. It is at the juncture of tributaries that we see a sudden increase in flow accumulation values. Therefore, the DELTA program identifies locations of flow junctures, and the map created by it is one of the data layers used to find locations of watershed pour points using the SEED program, which then can be used for watershed delineation with the WTRSHED program.

- Use the SEED program to automatically "seed" or find the pour points of the subwatersheds. Input the number of rows (lines), the number of columns (samples), the threshold value, the new "seed" filename in single quotes, the "delta" filename in single quotes, the "count" filename in single quotes, and the system name PRIME in single quotes. This program creates a new file, the "seed" file. The lower the threshold value, the more watersheds with smaller areas you will be

able to delineate. As a rule of thumb, to delineate watersheds of approximately 5 square miles, use threshold values of 1,500 or smaller.

WARNING:
Later in the procedure you will evaluate the length of the longest course of water flow in each subwatershed. The upper limit of this variable (named stream length in the Wildcat4 program) accepted by the program is 20,000 feet. Therefore, when generating subwatersheds it is important to make these units small enough so that the length of the longest course of flow in the subwatershed is not likely to exceed this value. This is an intuitive procedure, since the size of the basins varies from area to area, so several attempts might be necessary.

EXAMPLE:

```
OK, R IS>CONTRIB>HTAS>SEED

ENTER NL,NS,THRESHOLD,EDGES,SEED
FILE,DELTA FILE, COUNT

FILE,SYSTEM(UNIX,VMS,PRIME)

1334,1279,1000,0,'SEED.MAP','DELTA.
MAP','COUNT.MAP','PRIME'

122 BASINS WERE SEEDED

**** STOP
```

The SEED program finds the starting or "seed" points for automatic watershed generation at the outlets of potential stream tributaries on the drainage pattern modeled, using the HTAS. SEED accepts user input of the values (in number of cells) for the flow accumulation threshold above which the pour points of watersheds can be found. It also uses flow accumulation "count" values and "delta" values. For each cell where both the "count" value and the "delta" value are greater than the flow accumulation threshold, it assigns to this cell a unique positive value. This means that, for a threshold, the program will place a seed where the "delta" value, i.e., the flow accumulation increment between two cells, is above that threshold, and where the flow accumulation "count" value is above that threshold.

The first condition effectively places the "seed" where there is a juncture or tributary relationship between two potential streams, and the amount of flow input (the increment) from the stream is above the threshold. The second condition eliminates any streams which have a flow accumulation "count" value below the threshold as being too insignificant to have "seeds" created for them, thereby eliminating minor tributaries.

The cell that fits these criteria represents a pour point or a "seed" of an automatically delineated watershed and is given a positive value. The watersheds grown from each of these pour points will be assigned the value of the "seed" when the WTRSHED program is used. The background cells in the "seed" data set are assigned the value of -1.

- Delineate the subwatersheds using the WTRSHED program. Input the number of rows (lines), the number of columns (samples), the flow direction filename in single quotes, the seed filename in single quotes, and the system name PRIME in single quotes. The program rewrites the seed file as a watershed file.

EXAMPLE:

```
OK, R IS>CONTRIB>HTAS>WTRSHED

ENTER NL,NS,DIR FILE,MASK
FILE,SYSTEM(UNIX,VMS,PRIME)
1334,1279,'DIR.MAP','SEED.MAP','PRIME'

PASS    1
PASS    2
PASS    3
.       .
.
.
PASS   33
PASS   34
PASS   35

**** STOP
```

The WTRSHED program finds watersheds for "seed" cells that represent user-specified or automatically assigned pour locations. Delineation of watersheds requires both a flow direction data set and another starter or "seed" data set which represents watershed pour locations. The starter data set consists of background values of -1 in which the "seed" cell or groups of cells are inserted at the outflow points of the desired watersheds, with each start cell or group of cells having its own unique positive

NOTE:
The "seed" starter data set can be created automatically using SEED, or manually by generating the points in MOSS, RASTERIZing them to MAPS format, converting them using MAPSTOIDIMS and CONVERT to the direct access file format used by the HTAS, and snapping them to the HTAS modeled drainage pattern using RSNAP.

value. Using the flow direction data set, WTRSHED then iteratively reassigns the background values of cells in the starter data set to the value of the "seed" cell or groups of cells into which the background cells flow. The flow connectedness and direction of the background cells is identified from the flow direction map.

- CONVERT the seed file from direct format to Raster Transfer Format. Select 1 for conversion from direct format to raster transfer format, and then 2 for conversion from I*2 to transfer. You again need to put in number of rows (lines) and columns (samples).

EXAMPLE:

```
OK, R IS>CONTRIB>HTAS>CONVERT

Conversion desired (0=I*2 transfer-to-direct,
1=I*2 or I*4 direct-to-transfer):
        1

Direct access input image name:
        SEED.MAP

Transfer output image name:
        SHED.MAP.16

Direct-to-transfer datatype (2=I*2, 4=I*4):
        2

Lines in image:
        1334

Samples in image:
        1279

Converted      200 lines
Converted      400 lines
Converted      600 lines
Converted      800 lines
Converted     1000 lines
Converted     1200 lines

**** STOP
```

- CONVERT the COUNT file from direct format to Raster Transfer Format. Select 1 for conversion from direct format to raster transfer format, and then 4 for conversion from I*4 to transfer. You need to put in number of rows (lines) and columns (samples).

EXAMPLE:

```
OK, R IS>CONTRIB>HTAS>CONVERT

Conversion desired (0=I*2 transfer-to-direct,
1=I*2 or I*4 direct-to-transfer):
        1

Direct access input image name:
        COUNT.MAP

Transfer output image name:
        COUNT.MAP.32

Direct-to-transfer datatype (2=I*2, 4=I*4):
        4

Lines in image:
        1334

Samples in image:
        1279

Converted      200 lines
Converted      400 lines
Converted      600 lines
Converted      800 lines
Converted     1000 lines
Converted     1200 lines

**** STOP
```

- Import the watershed map which is currently in raster transfer format using the IMPORT command/WORD TYPE 7 option in MAPS. (Detailed instructions for the IMPORT command are in your MOSS/MAPS User's Manual.)

EXAMPLE:

```
IMPORT SHED.MAP.16 FORMAT IDIMS
WORD FOR SHEDS2000.MAP TYPE 7

ENTER THE FOLLOWING INFORMATION
FOR INPUT MAP
        NUMBER OF ROWS ?
        1334
        NUMBER OF COLUMNS ?
        1279
        NUMBER OF SUBJECTS ?
        (IF NOT KNOWN, KEY RETURN)
        CELL HEIGHT (IN METERS) ?
        30
        CELL WIDTH (IN METERS) ?
        30
        ENTER THE MINIMUM BOUNDING
        RECTANGLE MINIMUM X (WEST) ?
        610530
        MAXIMUM X (EAST) ?
        648900
        MINIMUM Y (SOUTH) ?
        4297860
        MAXIMUM Y (NORTH) ?
        4337880
        ENTER MAP PROJECTION
        INFORMATION PROJECTION(0-20) ?
        1
        ELLIPSOID(0-19) ?
        0
        LONGITUDE OF ANY POINT WITHIN
        THE UTM ZONE ?
        -112
        LATITUDE OF ANY POINT WITHIN
        UTM ZONE   12 ?
        38
        ENTER MAP DESCRIPTION
        INFORMATION MAP DESCRIPTION ?
        SUBWATERSHEDS AT 2000 CELL
        THRESHOLD
        STUDY AREA ?
```

TEST AREA

PROJECTION DESCRIPTION ?
UTM

DATE ?
11/15/93

SOURCE ?
J. BLASZCZYNSKI

VINTAGE ?
1993

**** STOP

- Import the COUNT map which is currently in raster transfer format using the IMPORT command/ DOUBLEWORD TYPE 8 option in the contributed software version of the MAPS IMPORT command contained in the IDIMS.RUN program.

EXAMPLE:

OK, R IS>CONTRIB>HTAS>IDIMS

SINGLE COMMAND VERSION OF MAPS
ONLY BYE AND IMPORT WILL WORK
IMPORT COUNT.MAP.32 FORMAT
IDIMS DOUBLEWORD ,
FOR COUNT.MAP TYPE 8

ENTER THE FOLLOWING INFORMATION FOR
INPUT MAP NUMBER OF ROWS ?
1334

NUMBER OF COLUMNS ?
1279

NUMBER OF SUBJECTS ? (IF NOT KNOWN,
KEY RETURN) CELL HEIGHT (IN METERS) ?
30

CELL WIDTH (IN METERS) ?
30

ENTER THE MINIMUM BOUNDING
RECTANGLE MINIMUM X (WEST) ?
610530

MAXIMUM X (EAST) ?
648900

MINIMUM Y (SOUTH) ?
4297860

MAXIMUM Y (NORTH) ?
4337880

ENTER MAP PROJECTION INFORMATION
PROJECTION(0-20) ?
1

ELLIPSOID(0-19) ?
0

LONGITUDE OF ANY POINT WITHIN THE
UTM ZONE ?
-112

LATITUDE OF ANY POINT WITHIN UTM
ZONE 12 ?
38

ENTER MAP DESCRIPTION INFORMATION
MAP DESCRIPTION ?

SUB-WATERSHEDS AT 2000 CELL
THRESHOLD STUDY AREA ?

TEST AREA

PROJECTION DESCRIPTION ?
UTM

```
DATE ?
        11/15/93

SOURCE ?
        J. BLASZCZYNSKI

VINTAGE ?
        1993

**** STOP
```

- Use the AREA command in MAPS or MOSS to produce an area table showing the acreage of each subwatershed. Check the size of the subwatersheds to see if their areas are below the 3,200 acre limit. Print out this information for later use.

Step 2. Label the subwatershed map.

Since MOSS/MAPS does not permit clear labeling of univalue areas that represent discrete units in raster data format and the subwatersheds imported into MAPS do not have labels yet, you need to label the subwatersheds. After labeling, prepare a drawing on which the names and the associated values are clearly represented. This permits you to know precisely which subwatershed you are working with and where it is located on the map.

- Label the subjects for the subwatershed map using the MAPS LABEL command. Make the cell value for a particular subwatershed the same as its subject label. For example, for subwatershed 1: cell value: 1.000, subject label: SW1; for subwatershed 2: cell value: 2.000, subject label: SW2.

```
EXAMPLE:
        ?
LABEL SHEDS2000.MAP

THIS IS A MAP WITHOUT SUBJECT LABELS.
WHAT WILL BE THE CHARACTER LENGTH
OF THE LABELS (16,32,64) ?
        16
```

```
LABEL SUBJECT MENU
        1 - FINISH
        2 - LIST
        3 - CHANGE
        4 - ENTER

SELECT ?
        4

FROM ID# ?
        1

THROUGH ID# ?
        22

22 SUBJECTS IN MAP SHEDS2000.MAP
ID      VALUE      FREQUENCY      SUBJECT

1       1. 0000    147653. 0

VALUE ?
        1

SUBJECT ?
        SW1

2       2. 0000    17159. 0

VALUE ?
        2

SUBJECT ?
        SW2
        .
        .
        .
LABEL SUBJECT MENU
        1 - FINISH
        2 - LIST
        3 - CHANGE
        4 - ENTER
SELECT ?
        1
OK  LABELED SHEDS2000.MAP
```

- The following is a sample CPL (macro) for LABELING the subwatershed map. You can use the CPL only after opening the map using LABEL and assigning the length of subject label (example above).

EXAMPLE:

```
COMO LABELSHED.COMO
TIME DATE &ARGS NUMBER &DATA MOSS
(project) (user) OPEN (project)

MAPS LABEL SHEDS2000.MAP
        3

&DO NUMBER := 1 &TO (number of
subwatersheds)
        %NUMBER%
        %NUMBER%
        SW%NUMBER%
        &END
```

NOTE:
For a particularly large area, it would be better to plot the map out on a plotter rather than printing it on a printer. However, one of two commands which plots raster maps on our current GIS, GENPLOT, requires that you provide a unique identification number for each of the subwatersheds and works very slowly on cell data. For example, to produce a plot of a map that contains 200 subwatersheds would require that you use GENPLOT five times, creating a plot for a different set of 40 subwatersheds each time and then merging the plots in GISPLOT. If you eventually want to produce a map showing subwatersheds, consider writing a CPL to do the process and run it as a batch job. Another alternative might be to use the DISPLAY command/META option in MAPS, which permits you to scale the map. If needed, you can ZOOM in on portions of a large subwatershed map and work with these sections.

Step 3. Locate the labels and values of subwatersheds on a printout of the subwatershed map.

You need to identify the location of watersheds which have a particular value and label. Unfortunately, the Bureau's current GIS does not plot the subject labels or values of cell (raster) type 7 (discrete) maps, so identification has to be done manually, using the QUERY command.

- Print out a map of subwatersheds using the PLOT command. Use the QUERY command to find the value of each of the subwatersheds. Visually compare the subwatershed map on the screen with your print, and write the subwatershed value on the print.

Step 4. Generate a map of longest stream segments for each subwatershed.

To obtain runoff information within a subwatershed, you need the length of the longest channel within that subwatershed. The current software requires that you

GENERATE line segments that represent streams for each subwatershed since there is no method to convert raster data into vector data.

- Display the edited subwatershed boundaries over a display of the "count" map you developed when you generated the boundaries with the HTAS. Displaying ranges of values from the "count" map creates an image of the drainage network for the study area. You might also want to display the hydrography layer of the DLG if available and review its correspondence to modeled drainage patterns in the "count" map. If you lack DLG hydrography data for a subwatershed, generate a line over the central longest drainage in the subwatershed.

- Use the GENERATE command to trace along the main drainage within each subwatershed. This creates line segments that represent the course of main water flow in the subwatershed. Assign the subwatershed subject label to the line segments, so that there is a clear correlation between the basin and the course of flow. For large areas generate line segments in sections of the map by ZOOMing in on the areas you are working on, and then MERGing the resultant maps. (MOSS commands used: WINDOW, ZOOM, PLOT, GENERATE, MERGE).

EXAMPLE:

ENTER COMMAND ?
GENERATE

What do you wish to call the new map ?

: LENGTHS1

Enter mapname for the template header
(CR=quit)
: DLGWATER.MAP

ENTER SOURCE OF MAP
: J. BLASZCZYNSKI

ENTER CREATION DATE []
: 1/15/92

ENTER STUDYAREA NAME [U060. 381]
: EXAMPLE

ENTER DESCRIPTION
[DRAINAGE BASIN; TEST WASH;
OCCULAR 1:24,000

:

LONGEST CHANNEL SEGMENTS FOR
SUBWATERSHEDS -MAP 1 IS THIS HEADER
INFORMATION CORRECT [Y]
: <CARRIAGE RETURN>

How many subjects for new map? [20]
: <CARRIAGE RETURN>

Enter data type this map is to be:
1 - Point 2 - Line 3 - Polygon
: 2

Keyboard or Cursor input (K/C) [C]
: <CARRIAGE RETURN>

Line chosen.
You may: Quit (Q CR=Continue)
: <CARRIAGE RETURN>

Enter subject for this item
[ ]:
SW1

Press space bar to enter points for item.
Undo with "U" key.
toggle Smooth with "S" key
reFresh with "F" key
Terminate with "T" key
option Help with "H" key
CURSOR INPUT

NOTE:
Even if you have a DLG hydrographic layer for the study area, the DLG streams might not have a tributary for each of the subwatersheds. To understand why there are subwatersheds without tributaries, you should study the HTAS manual sections on automatic delineation of watersheds. Essentially, each subwatershed identified with the HTAS is a discrete basin or a section of a discrete basin with water flowing downslope along the steepest path. This does not mean, however, that a discrete stream will develop in each subwatershed. The DLGs made from aerial photographs or maps show existing streams only, while the modeled drainage patterns show likely water paths based on the shape of the landscape. To model runoff from each subwatershed, we need to estimate the length of the longest path in each basin, which is provided for us by the drainage pattern map modeled using the HTAS.

WARNING:
The upper limit of the course of water flow length (named stream length in the Wildcat4 program) accepted by the runoff generation program is 20,000 feet. Therefore, when generating subwatersheds, it is important to make these units small enough so that the lengths of the longest course of flow in the subwatershed are not likely to exceed this value.

```
Line chosen.   You may:  Quit (Q
CR=Continue)
        :<CARRIAGE RETURN>

Enter subject for this item [SW1] :
        SW2

Press space bar to enter points for item.
Undo with "U" key.
toggle Smooth with "S" key
reFresh with "F" key
Terminate with "T" key
option Help with "H" key
        CURSOR INPUT

Line chosen.   You may:  Quit (Q
CR=Continue)
        : Q

**** STOP
```

Step 5. Obtain a list of longest stream lengths.

Obtain the list of lengths for each longest course of flow segment in each subwatershed using the LENGTH command in MOSS.

EXAMPLE:

```
ENTER COMMAND ?  LENGTH 1

BLM/DSC                    01/23/92                    PAGE  1

LENGTH SUMMARY FOR MAP LENGTHS1  ACTIVE MAP NO. 1
```

SUBJECT	LENGTH	FREQUENCY	PERCENT
SW1	1. 68	1	44. 72
SW2	2. 08	1	55. 28
TOTAL (IN MILES)	3. 76	2	100. 00

```
**** STOP
```

- Convert the miles to feet to use the lengths with the Wildcat4 program.

Step 6. Prepare a soil hydrologic groups map.

To generate a runoff hydrograph for each watershed, you have to know the curve number and areal extent of the hydrologic response units (HRUs) in each subwatershed. The method to develop an HRU map described here is based on the work of R. H. McCuen (1982) (excerpt in Appendix A). To do so you must first prepare a raster map of soil hydrologic groups from a soil units map digitized from a soil survey for the study area.

Soils are classified into hydrologic groups based on the minimum rate of infiltration obtained for bare soil after prolonged wetting. The soil hydrologic groups are used to determine runoff curve numbers. Soil surveys usually contain information on the hydrologic group or groups of a particular soil type. If more than one hydrologic group is assigned to a soil type, choose the group that best represents the soil type.

- Use the RASTERIZE command to rasterize the vector soil map by subject or item. Assign a value of 1 to Group A, 2 to Group B, 3 to Group C, and 4 to Group D, using the RENUMBER command.

Step 7. Prepare a map of range condition units.

- Prepare a map of range condition units, which describe the condition of the land in terms of a qualitative estimation as to whether it is poor, fair, or good (based on R. H. McCuen, 1982 - copy of discussion included in Appendix A). The base map used for assigning range condition could be a vegetation map or a soils map. An experienced resource specialist well acquainted with the study area is invaluable in making these estimates.

- Use the RENUMBER command to assign the conditions POOR, FAIR, and GOOD to groups of polygons or individual polygons on the base map by assigning a value of 10 to POOR areas, a value of

NOTE:
Generally the source of soil maps is the soil surveys for the area produced by the USDA Soil Conservation Service in association with other agencies. Occasionally you will find that more than one soil hydrologic group is assigned to a single soil type represented on the map. To deal with this situation, select the soil hydrologic group of the most predominant soil type, calculate a weighted average, or try to refine the soils map by intersecting it with a slope class map, since certain types of soils can be related to a particular slope class. There is still no established soil survey enhancement methodology, although one that utilizes combined remote sensing and GIS methods is being researched at the Service Center as the Soil Landscape Analysis Project (SLAP) (Amen and Foster, 1987). Whichever method you select or devise, make sure that it is applied consistently throughout the area of study, and keep records of your approach for future reference.

20 to FAIR areas, and a value of 30 to GOOD areas.

Step 8. Prepare a Hydrologic Response Units* (HRU) *map.

- Combine the soil hydrologic groups map with the range condition map to prepare a map of hydrologic response units (HRUs) consisting of areas that contain units with unique curve numbers (based on R. H. McCuen, 1982 - see Appendix A).

- Intersect the soil hydrologic groups map with the range condition map by **adding** the two together using the MATH command. The product is a map of areas with different cell values for each intersection of a soil hydrologic group and watershed condition unit. These cell values are presented in the table below.

	Group A	Group B	Group C	Group D
Poor	11	12	13	14
Fair	21	22	23	24
Good	31	32	33	34

- Each intersection of a soil hydrologic group unit with a range condition unit creates a hydrologic response unit (HRU); a unique curve number can be assigned to it. Assign the curve number value to the cell value representing the corresponding HRU using the RENUMBER or EXTRACT commands. The results are shown in the table on the following page (Commands used: RENUMBER or EXTRACT).

- The map product is a Hydrologic Response Unit (HRU) Map which contains areas with the cell value equivalent to a curve number.

	Group A	Group B	Group C	Group D
Poor	68	79	86	89
Fair	49	69	79.1	84
Good	39	61	74	80

- LABEL clearly the subjects of the HRU map. An illustration of subject labels is provided in the example below.

EXAMPLE:

Sample description of subjects in a curve number or HRU map) ?

DESC HRU. MAP SUBJECT

7 SUBJECTS IN MAP HRU. MAP

ID	VALUE	FREQUENCY	SUBJECT
1	79.0000	27927.0	79/POOR/B
2	86.0000	30097.0	86/POOR/C
3	89.0000	50334.0	89/POOR/D
4	69.0000	3360.0	69/FAIR/B
5	78.0000	1605.0	78/FAIR/C
6	84.0000	31211.0	84/FAIR/D
7	61.0000	879.0	61/GOOD/B

Step 9. *Prepare a map of subwatershed* HRUs *and generate a list of acreages for each.*

- Intersect the HRU Map with the subwatershed map using the INTERSECT command to generate the subwatershed HRU map. Use AREA to calculate the areas for units of this map. Print out the report. You now have a list of subwatersheds, the HRUs they contain, and the area of each HRU, all of which will be used as input data to the SCSCN PC program.

WARNING:

Sometimes the intersection of a soil hydrologic group and a watershed condition unit might have the same curve number. The Bureau's raster GIS, MAPS, treats all areas with the same value as the same type of unit. The resource specialist should decide whether to treat the areas as the same HRU or a different HRU. To maintain the areas as different HRUs, change the curve number slightly by adding .1 or a similar number to the right of the decimal point. As separate subjects on the HRU map, you have the record of which association between soil hydrologic groups and watershed condition unit made the HRU. For example, in the above table, since there were two HRUs with a curve number of 79, one of the numbers was changed to 79.1. This is useful mainly for recordkeeping. When you input these data into the SCSCN watershed file, revert the number back to its original value; i.e., the 79.1 would revert to 79.

EXAMPLE:

Sample printout of the subjects for a sub-watershed HRUs map:

DESC HRUSHED.MAP SU

144 SUBJECTS IN MAP HRUSHED.MAP

ID	VALUE	FREQUENCY	SUBJECT
1	1. 1000	628. 0	SW1 79/POOR/B
2	1. 7000	386. 0	SW1 61/GOOD/B
3	1. 6000	166. 0	SW1 84/FAIR/D

(etc.)

Sample print-out of the area table for a sub-watersheds HRU map.

?

AREA HRUSHED.MAP

144 SUBJECTS IN AREA SUMMARY FOR MAP HRUSHED.MAP

ID	VALUE	AREA	FREQ.	%	SUBJECT
1	1. 1000	628.00	628. 0	1. 18	SW1 79/POOR/B
2	1. 7000	386.00	386. 0	0. 28	SW1 61/GOOD/B
3	1. 6000	166.00	166. 0	1. 50	SW1 84/FAIR/D

(etc.)

Step 10. Prepare a list of average slopes for each subwatershed.

- Develop a slope map for the study area using the SLOPE command, or use the slope map already developed in the RUSLE/GIS procedure.

- Apply the TOTAL command to obtain average slope values for each subwatershed.

EXAMPLE:

TOTAL (slopemap) BY (sub-watershed map) FOR (total report)
Sample printout of a TOTAL report:

TOTAL REPORT PAGE 1

MAPNAME	FACTOR	CELL SIZE
SAGERS. SLPSUM1A	1. 000	1. 000
BY SAG2000.SHED1A		

SUBJECTS	TOTAL	FREQUENCY	AREA	PRODUCT	AVERAGE
SW1	205585.	4088.	4088.	205584.966	50.290
SW2	363865.	7592.	7592.	363864.388	47.927
SW3	306380.	6171.	6171.	306379.805	34.648
SW4	134985.	6137.	6137.	134985.242	21.995
SW5	229045.	5915.	5915.	229044.552	15.723
.....					
.....					
.....					
SW184	162706.	3478.	3478.	162706.400	6.782
TOTAL	2462050.	151057.	151057.	2462049.209	16.299

(BACKGROUND ACRES = 228230.)

Step 11. Prepare a table of subwatershed data for input into the* DOS WILDCAT4 *program.

You have now finished preparing the data needed to generate the runoff hydrograph for each subwatershed in the area of study. For each subwatershed, this information includes the average slope, length of the longest channel (convert to feet), number of HRUs in the subwatershed, HRU areas (convert to square miles), and curve numbers.

- Transfer these data to a table for each subwatershed.

Step 12. *Generate watershed and storm files in the* DOS WILDCAT4 *program.*

- Use the Wildcat4 program to create a watershed file for each of the subwatersheds.
- Input storm information for each storm that you want to model into the Wildcat4 program, creating storm files.

Step 13. *Generate runoff hydrographs from watershed and storm data using the* DOS WILDCAT4 *program for each subwatershed.*

- Generate a runoff hydrograph file for each subwatershed using the Wildcat4 program and print out the short version of the file. The printout is one page containing the watershed and storm data, volume of runoff (Q) in acre-feet, peak flow (q_p) in cubic feet per second, and other information.

EXAMPLE:

A short version of the runoff hydrograph file generated by the Wildcat4 program.

```
                    SCS STORM HYDROGRAPH

sw31                                                          Page No. 1

==================================================================================
                  INPUT SUMMARY FOR WATERSHED: sw31

 STORM:                              WATERSHED:

    DEPTH =    0.90 inches                   AVG LAND SLOPE =      11.4  %
 DURATION =    6.00 hrs              LENGTH LONGEST CHANNEL =   3590.   ft
  DISTRIB =  SCS TYPE B

                                     HRU No.   AREA (sq mi)    CN
                                     -------   ------------   ------
                                        1          1.13       89.00
                                        2          0.65       86.00
                                        3          0.24       79.00
                                        4          0.03       78.00
                                        5          0.28       84.00
==================================================================================


==================================================================================
                 OUTPUT SUMMARY FOR WATERSHED: sw31

        TOTAL DRAINAGE AREA =      2.330  sq mi
                         CN =     86.39
     TIME OF CONCENTRATION =      0.352
       INITIAL ABSTRACTION =      0.3151 inches
      TOTAL RUNOFF DEPTH =       0.0525 inches  (   6.52 acre-ft)
                 PEAK FLOW =    122.10   cfs    ( 0.0812 ign)
                 PEAK TIME =      2.72   hrs
==================================================================================
```

C. Steps of Storm Sediment Yield Prediction with GIS using MUSLE

Step 1. Generate runoff hydrographs for subwatersheds in the study area using Wildcat4.

- Follow the procedures outlined in Chapter II, Section B, above to generate runoff hydrographs for subwatersheds in the study area. Create a table of values for the volume of runoff (Q) in acre-feet and peak flow (q_p) in cubic feet per second for each subwatershed. These values are provided on the printout of the short version of the hydrograph file.

Step 2. Create a volume of runoff and peak flow maps.

- Assign the Q values to each subwatershed in the original subwatershed map created from DEMs using the HTAS, thus generating a Q-value map (Q-map).

- Assign the q_p values to each subwatershed to create a q_p-value map (Q_p-map) (MAPS command used: RENUMBER).

Step 3. Create a runoff factor/subwatershed map.

- Create a runoff (R) factor map (R-map) by relating the Q-value map and the q_p-value map through the runoff factor equation, or $R = 11.8 (Q\text{-map} * q_p\text{-map})^{.56}$ (MAPS command used: MATH).

EXAMPLE:

MATH (11. 8 ((Q-map * q_p-map) ** 0. 56))
FOR (R-factor map)

Your map now contains one value for the R-factor for the entire subwatershed.

Step 4. *Prepare a map that holds runoff (R) factor values for each acre of a subwatershed.*

At this point you have a map that holds a runoff factor value for the entire subwatershed; however, you want to relate this map to maps of the distribution of other factors of the MUSLE. These maps contain factor values for areas that are soil or vegetation units, or, in the case of the terrain factor, individual values for each cell. To relate these maps together it is best to create a map that contains runoff factor values per cell, and a convenient cell size is one acre.

- Use the RESAMPLE command and the default AVERAGE option to change the size of the runoff factor map to one-acre cell size.

To obtain a map that holds runoff factor values for each acre cell, you need to divide the runoff factor value of each subwatershed by its size in acres. This assumes that the runoff factor is evenly distributed throughout each subwatershed and that all variation in sediment yield within a subwatershed comes from the other factors. However, unless variation in rainfall can be modeled for smaller units, stay with this assumption of even distribution.

- Develop a map that holds values per subwatershed which represents the area of that subwatershed. This can be accomplished for **maps with acre-sized cells** using the SIZE command.

EXAMPLE:

SIZE (subwatershed map)
FOR (subwatershed area map)

- Obtain a map that shows the fraction of the runoff factor for each acre of each subwatershed or R-per-acre map by dividing the subwatershed runoff factor map by the subwatershed area map (SIZE map) (MAPS commands used: SIZE, MATH).

EXAMPLE:

```
MATH ( (R-factor map) /
 (subwatershed area map) ) ,
FOR (R-factor/acre map)
```

Step 5. *Generate the* K, LS, C, P *factor maps.*

Follow the procedures outlined in Chapter II, Section A on the RUSLE/GIS methodology to develop the K, LS, C, and P factor maps. The LS factor map in particular should be generated using the original DEM map without changing its 30x30m cell size, so as not to loose the accuracy of the terrain information while calculating the terrain factor.

- Change the cell size of all maps to one acre using the RESAMPLE command with the default AVERAGE option.

The main reason for not doing all RUSLE/GIS or MUSLE/GIS processing using maps of one-acre cell size is because the 30x30 meter cell size is important for better resolution of information about terrain (in the DEMs). DEMs at 30x30 meters provide information on the slope, slope length, L and S factors, and average slope per watershed.

Step 6. *Generate a sediment yield per acre map.*

- Multiply all the factor maps together to obtain a sediment yield per storm map. This map shows the modeled storm sediment yield in tons. Because each cell of the map is acre sized, the value of each cell represents storm sediment yield per acre.

EXAMPLE:

```
MATH (R-fact. /sub-watershed/acre map) ,
* (K acre map) * (LS acre map) ,
* (C acre map) * (P acre map) ,
FOR (Sediment Yield/acre map)
```

NOTE:
Be aware of the difference between the RUSLE sheet and rill erosion map and the MUSLE sediment yield map.

The RUSLE/GIS Interface produces a map with values for sheet and rill soil erosion in terms of tons/acre/year. Each cell of the map contains a value for erosion in tons/acre/year irrespective of the actual size of the cell. If you change the size of the cells to one acre and then TOTAL the erosion values over some interested area, you obtain total sheet and rill erosion in tons per year. By changing the size of the cells to one acre, you factor out the "per acre" units for erosion, i. e., each of your acre cells produces X tons during the average year.

The MUSLE procedure provides sediment yield in tons per subwatershed for a particular subwatershed and a particular storm (tons/subwatershed). Each of the one-acre size cells contains information in terms of tons coming off this acre's particular subwatershed, for the particular storm event being modeled.

Step 7. Obtain sediment yield summaries for each subwatershed.

- TOTAL the values over the subwatershed map to obtain sediment yield values in tons for each subwatershed. These values represent the changes in K, L, S, C, and P factors across each subwatershed, based on the assumption that the runoff (R) factor is the same for each acre of the subwatershed.

EXAMPLE:

TOTAL (Sediment yield/sub-watershed/acre map),
BY (sub-watershed map) ,
FOR (Sediment yield/sub-watershed total report)

Sample sediment yield total report (the numbers are purely illustrative and do not represent actual sediment yield values):

```
TOTAL  REPORT                                          PAGE  1

MAPNAME              FACTOR    CELL SIZE
SEDY.2YRORIG1A        1. 000     1. 000
BY SHED2000.MAP1A
```

SUBJECTS	TOTAL	FREQUENCY	AREA	PRODUCT	AVERAGE
SW1	150.	188.	188.	850.058	0.208
SW2	645.	3592.	3592.	1644.765	0.217
SW3	888.	3171.	3171.	2888.190	0.468
SW4	199.	2137.	2137.	198.930	0.032
.					
.					
.					
SW184	590.	4717.	4717.	590.276	0.125
TOTAL	40710.	151057.	151057.	40710.455	0.270

(BACKGROUND ACRES = 228230.)

- TOTAL sediment yield values over any other area, such as a vegetation or a soil unit, to obtain sediment yield values for that area.

Step 8. Further analyses and generation of products for decision-making.

Your product is a detailed map of sediment yield for each of the subwatersheds in your study area for a particular storm event. Using the MUSLE/GIS procedure, you can model the runoff and sediment yield from extreme storm events; site or evaluate sitings of potential structures, such as dams and reservoirs; estimate how long it might take for the reservoir to fill up with silt; and run numerous other applications.

Chapter 3
GIS/HTAS Modeling of Management Alternatives with RUSLE and MUSLE

Introduction

This final chapter of the manual describes modeling of the effects of various management alternatives for portions of the area under study. Two main techniques will be discussed: modeling of the effects of vegetation improvement by changing the surface cover factor in the RUSLE, and modeling of the effects of placing a dam to prevent or slow down soil and water transport. This chapter assumes that the GIS specialists are thoroughly acquainted with raster processing in MAPS and the capabilities of the Hydrologic Terrain Analysis Software (HTAS), as well as previous sections of this manual. Therefore, the following discussion is general and does not get into the step-by-step instructions that were provided in Chapter II.

The first example involves a simple procedure to evaluate the effects of vegetation improvement on any mapped area, such as a vegetation unit, a soil unit, a watershed, or any other area you define. The second involves looking at the flow patterns on the landscape to decide on a general area for a placement of a dam. Using the capabilities of the HTAS we can determine the watershed or the drainage area for dams placed in several strategic locations. In addition, we can estimate the approximate volumes of reservoir storage for these dams and the areal extent of the reservoirs, should they become filled with water or sediment.

To reiterate, it is essential that the GIS specialists performing this modeling become well acquainted with the capabilities of the Hydrologic Terrain Analysis Software, so that proper and imaginative use can be made of it in the modeling process. In fact, the primary intent of this last chapter is to provide the general outline of these procedures, assuming that you have now become an expert GIS/HTAS user and do not need the detailed pre-

NOTE:
It is important to remember that the capabilities provided by the RUSLE sheet and rill soil erosion prediction, SCS Curve Number storm runoff prediction, and the MUSLE sediment yield prediction, when combined with the capabilities of the GIS and the HTAS, leave room for more detailed and imaginative modeling than can be described within the scope of this manual. For example, the HTAS permits delineation of surface depressions based on the topography represented by a Digital Elevation Model. Some of these surface depressions might be artifacts related to the quality of the elevation model, so groundtruthing is essential to make sure that we are not dealing with imaginary concavities in the landscape. However, if the depressions are real, they become sediment sinks, so adding the locations of these sediment sinks to our soil erosion or sediment yield map can help us to understand better the flow of sediment through the landscape.

sentation style of Chapter II of this manual. However, we have tried to make the discussion of these methods as clear as possible in the following sections.

A. Vegetation Improvement

Vegetation improvement can be modeled quite simply by changing the input values used to derive the surface cover (C) factor used in the RUSLE or MUSLE equations. When a new C-factor value is placed in a C-factor map and this map is then multiplied with the other factor maps and the rainfall (R) factor value, we will obtain a new erosion value for any particular area that shows the potential results of vegetation improvement on soil erosion. This simple method is summarized in the following steps:

1. Choose the area you feel is in need of vegetation improvement. First examine the surface cover factor component values, which include the percentage and average height of vegetation cover; the percentage of rock, gravel, litter, and vegetation; the root mass in the top 4 inches of soil; and roughness values associated with field conditions that were used to derive the original C-factors for this area. Then estimate the effect of potential changes on these values. Finally, input the new values into the RUSLE program to calculate the new C-factor values for improved vegetation conditions.

2. To eliminate problems that might occur when you are renumbering vegetation areas with new C-factors using the subject renumber method (e.g., a particular vegetation type consists of several polygons spread throughout the entire study area and you want to change only one of them), EXTRACT the particular area you want to improve from the rest of the map and work with it independently (MAPS commands used: EXTRACT, MATH, and/or CATEGORIZE).

3. Assign new C-factor values for each of the vegetation units in the new improvement area map you just generated, creating a C-factor map (MAPS command used: RENUMBER).

4. Combine the map of the new improvement area with the original C-factor map by COVERING the original C-factor with the new map. The result will be that all the old C-factors will appear as they were, except in the improvement area. This step is optional and important only if you want to have a new map for the entire area you were originally working with. If you are interested in working only with the improvement area, disregard this step (MAPS command used: COVER).

5. Calculate the new erosion map by multiplying all the factor maps and the R-factor value together as described in the section on the RUSLE/GIS method.

B. Calculating the Watershed of a Dam

This is a more complex procedure than estimating the effects of vegetation improvement on a particular area, so it more fully demonstrates the power of all of the tools described in this manual. The procedure utilizes the capabilities of MOSS vector and MAPS raster GIS as well as HTAS. Knowledge of all these systems is essential. For many applications, knowledge of a potential drainage area for a dam or another water retention or detention structure might be adequate without any further calculations being necessary.

The general steps for calculating the watershed for a dam are as follows.

1. Once the general area to be worked with has been selected, display the flow patterns modeled from the DEM by using the HTAS and the actual streams obtained from USGS Digital Line Graphs or other sources on the screen. You might also want to display all or portions of the soil erosion or sediment yield maps to identify critical soil detachment and transport areas. After evaluating the flow, soil erosion, and sediment yield patterns, place dams in several potential locations you are interested in by GENERATing lines that represent the dams. In

WARNING:
It should also be remembered that the watersheds, depressions, and drainage patterns we have delineated using the HTAS come purely from terrain information that represents the entire variability of the landscape as a single number. This number approximates the elevation of a 30x30 meter area on the ground. The actual flow of water and sediment through the landscape is influenced not only by these macroscopic trends in the terrain morphology as approximated in a DEM, but also by the microrelief that is not represented in the elevation model, as well as the hydrologic properties of the soil and surface cover. Therefore, our results are only approximations, as is always true of a model, although they are finer than if traditional methods were used without the help of GIS.

choosing these locations, you might first want to check the cross-section of the potential dam by using the PROFILE command (MOSS commands used: PROFILE and GENERATE).

2. Use the RASTERIZE command to create a raster map (type 8 or continuous) version of these features. Your will obtain a map where each "dam" is represented by a set of cells with a unique number assigned to them (MAPS command used: RASTERIZE).

3. From the raster map of potential dams, you now need to create a "seed" map (see the HTAS manual on delineation of watersheds for user-generated pour locations). This is accomplished by RENUMBERing the zero valued cells of your type 8 continuous map to the value of -1, which is the background value required by the HTAS. Then follow the procedures described in the HTAS manual for delineating watersheds for user-defined pour locations. The procedures start with converting the MAPS raster map you now have and then using it as a seed map in the WTRSHED program, IMPORTing it back into MAPS as a type 7 discrete map. This results in a map of watersheds for the dams. Now you can calculate their areas or run the SCS Curve Number method and MUSLE method to determine runoff and sediment yield for a particular storm for this specific watershed. You can also summarize the total soil erosion calculated using the RUSLE/GIS method for this watershed as well (Commands used: RENUMBER and IMPORT in MAPS, and HTAS commands as described in both the procedural and reference sections of the HTAS manual).

C. Calculating the Area and Volume of the Reservoirs for the Dams

Where a dam is large enough that its extent can be modeled using 30x30m DEM data, or if DEMs with higher

resolutions are available, it might be worthwhile to calculate the area and volume of the reservoir created by the dam.

1. Follow steps 1 and 2 of Section B above.

2. Once you have the raster map of dams, you should sample the DEM for the area for elevation values at several locations on each of the dams (at least the edges and the center). This can be done by ZOOMing in on the dams and QUERYing the DEM using a cursor. From these, you can estimate the elevation of the spillways so that you will not have their tops higher than the elevation of the edges of the dams (Commands used: ZOOM and QUERY in MOSS or MAPS).

3. Once the heights of the spillways for each of the potential dams have been identified, RENUMBER the values in cells representing each of the dams with the appropriate spillway elevation (MAPS command used: RENUMBER).

4. Convert the *original DEM* using the conversion procedures described in the data conversion section of the HTAS manual, and then fill it using the CONCAVE program as described in the conditioning stage section of the HTAS manual. IMPORT the *filled DEM* back into MAPS, again following the procedures described in the HTAS manual, and name it clearly to distinguish it from the original DEM.

5. Use the COVER command to cover the *filled DEM* with the newly created dams map in which the dams are represented by the height of their spillways. This will result in a DEM that has raised areas representing potential dams, in effect creating a closed depression where before there was an open valley. If viewed using 3-D in close up, you would see a valley which ends with a barrier. In this way the dam has been simulated within, of course, the limitation of the 30x30 m resolution of a DEM (MAPS command used: COVER).

WARNING:
Pay attention to the parameters you used while running CONCAVE. These parameters describe the size of the box and the overlap (discussed in detail in the HTAS manual). The overlap has to be larger than the largest depression you expect to find in the landscape, so here it is advisable to use large box and large overlap values.

NOTE:
The reason a filled DEM is necessary will become apparent in the following steps. Essentially, we will use the HTAS filling program CONCAVE to fill the depressions that represent the reservoirs of dams, and we want to clearly distinguish these depressions from other depressions found naturally in the landscape.

NOTE:
The CLUMP command can be used to clump all the depressions on a DEM that have been identified by subtracting the original DEM from the filled DEM. Once you have obtained unique positive values for each clump of cells representing a depression, you can follow the watershed delineation procedures described in Section B above to delineate a watershed for each one of these depressions, or the ones you consider to represent genuine features of the landscape. By obtaining a watershed for each of these, you can assume that all of the soil eroding in the area of this watershed will actually wind up in the depression until it fills it. It is also possible to estimate volumes of these depressions, and therefore how long they might take to be filled, depending on erosion rates by using the procedure outlined below.

6. Now its time to convert the *filled DEM modified through addition of the possible dams*, using the conversion procedures described in the HTAS manual. Once in the HTAS format, you will process the DEM again by using the CONCAVE program, and then IMPORT it back into MAPS. When using CONCAVE, keep the same parameters that were used on the *original* DEM. The product is *a DEM with filled depressions that represent the reservoirs to be created by potential dams.*

7. Subtract the newly created *type 8 continuous filled reservoir map* from the filled DEM. The product will be a map of the reservoirs, with each cell of the reservoir representing the depth or the height of the column of water for each 30x30 m area of the reservoir. (More accurate results could, of course, be obtained with DEMs of higher resolution, such as the ones produced from SPOT satellite imagery, which have a resolution of 10x10 m.) What you now have is a type 8 continuous map consisting mostly of zero values, with positive values representing the lens created by the filling process. The lens has an irregular bottom and a horizontal surface. (MAPS command used: MATH).

8. Use the CLUMP command to create a *type 7 discrete reservoir map* from your *type 8 continuous reservoir map*. CLUMP will give each group of cells representing a reservoir a unique positive number so that you can distinguish them from each other; in other words, your reservoirs will now be numbered 1, 2, 3, etc. (MAPS command used: CLUMP).

9. Multiply your *type 8 continuous reservoir map* by 30 x 30, or by 900. This is a simple application of a volume formula for a column of water. The idea is that the values of the *type 8 reservoir map* represent the depth, or the height, of the column of water. The formula for the volume of a parallelepiped is height * width * length. The width and length are both 30 m, since we are dealing with square cells. We now have a map in which the cells representing the reservoirs have values which correspond to their volumes (MAPS command used: MATH).

10. Use the TOTAL command to summarize the values of the *type 8 continuous reservoir volume map* over the type 7 discrete reservoir map. The product will be a table, as in the example below, that will provide various summaries for the reservoirs. The columns we are interested in are the AREA column, the SUM column, and perhaps the AVERAGE column. We now have not only a map showing the total extent of the reservoirs, but also a table showing their area and volume that can be used for other hydrologic calculations. We can play additional "what-if" games by, for example, contouring the *depth reservoir maps* or the *volume reservoir maps* to show the extent of the various levels and volumes of water.

EXAMPLE:

```
TOTAL RESERVOIRST8 BY RESERVOIRT7


TOTAL  REPORT                                                    PAGE  1

MAPNAME            FACTOR    CELL SIZE
RESERVOIRST8        1.000     0.222
BY RESERVOIRT7
```

SUBJECTS	TOTAL	FREQ.	AREA	PRODUCT	AVERAGE
RESERVOIR 1	2423700.	188.	42.	539018.335	12892.021
RESERVOIR 2	3769200.	386.	86.	838250.571	9764.767
RESERVOIR 3	3038400.	271.	60.	675724.433	11211.808
TOTAL	9231300.	845.	188.	2052993.339	10924.615

```
( BACKGROUND ACRES  =    38546. )

OK  TOTALED
```

Epilogue

One of the major skilled uses of a GIS, beyond developing simulation models of real situations, is the ability to play "what-if" games and calculate the effects of various scenarios. The above discussion shows only a small sample of what can be accomplished.

For example, the watershed delineation and reservoir modeling methods described above could be used to provide simulations of various hydrologic conditions as well as to help locate and design dams or various other water and soil retention and detention structures. Using the tools described here to model runoff from an extreme 100-year storm might help us design dams that would manage to hold the influx of water from such an intense precipitation event.

This manual leaves many of these possibilities unexplored. However, we hope that by providing you with some basic tools, you will find methods to apply them imaginatively to problem solving and decisionmaking for land management projects in your backyard.

We would like to hear from you about your successes as well as your difficulties in using these tools; we are available to provide help, so please don't hesitate to call us. On our part, we will continue to try to improve the methods we provide for your use. Please also share the methods you have developed with us, so that we can help you to distribute them throughout the rest of the Bureau. For more information, please contact:

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Appendix A
Curve Number References

Table 9.1.--Runoff curve numbers for hydrologic soil-cover complexes

(Antecedent moisture condition II, and $I_a = 0.2\ S$)

Land use	Cover: Treatment or practice	Hydrologic condition	Hydrologic soil group: A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	"and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	"and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes 1/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	"and terraced	Poor	63	73	80	83
	"and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		---	74	84	90	92

1/ Close-drilled or broadcast.
2/ Including right-of-way.

Table 9.1A.--Runoff curve numbers for hydrologic soil-cover complexes for conservation tillage and residue management

(Antecedent moisture condition II, and $I_a = 0.2S$)

Land use	Cover: Treatment or practice	Hydrologic condition 1/	Hydrologic soil group: A	B	C	D
Fallow	Conservation tillage	poor	76	85	90	93
	Conservation tillage	good	74	83	88	90
Row crops	Conservation tillage	poor	71	80	87	90
	Conservation tillage	good	64	75	82	85
	Contoured + conservation tillage	poor	69	78	83	87
		good	64	74	81	85
	Contoured + terraces + conservation tillage	poor	65	73	79	81
		good	61	70	77	80
Small grain	Conservation tillage	poor	64	75	83	86
	Conservation tillage	good	60	72	80	84
	Contoured + conservation tillage	poor	62	73	81	84
		good	60	72	80	83
	Contoured + terraces + conservation tillage	poor	60	71	78	81
		good	58	69	77	80

1/ For conservation tillage poor hydrologic condition, 5 to 20 percent of the surface is covered with residue (less than 750 #/acre row crops or 300 #/acre small grain).

For conservation tillage good hydrologic condition, more than 20 percent of the surface is covered with residue (greater than 750 #/acre row crops or 300 #/acre small grain).

NOTE: Percent cover should be estimated at the time of year storms occur.

Appendix B
Table of Inputs into SCSCN, NEWHYD, or WILDCAT4 Watershed Files

Sub-basin ID	Average Slope	Longest Channel Length	Number of HRUs	HRU		HRU		HRU		HRU		HRU		HRU		HRU	
				mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN

Sub-basin ID	Average Slope	Longest Channel Length	Number of HRUs	HRU		HRU		HRU		HRU		HRU		HRU		HRU	
				mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN	mi^2	CN

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13. ABSTRACT *(Maximum 200 words)*

This report describes methodologies developed for interfacing the Revised Universal Soil Loss Equation (RUSLE), the Soil Conservation Curve Number (SCSCN) method, and the Modified Universal Soil Loss Equation (MUSLE) with Geographic Information Systems (GIS) to quickly and effectively estimate the potential sheet and rill erosion, runoff, and sediment yield for large areas. Since the processes related to water soil erosion are diffuse, occur at varying rates over the landscape, and depend on a variety of factors that change continuously, a direct measurement of soil erosion is impractical. Researchers therefore have turned to using prediction models such as the USLE, RUSLE, MUSLE, and SCSCN to inventory erosion and calculate runoff and sediment yield for local and regional assessments. Geographic Information Systems provide the means to quickly extract, analyze, and relate the geographically distributed data on various environmental parameters required by these models. The report provides first a brief overview and then a detailed step-by-step instructions on the GIS procedures used to interface with the models. The last chapter discusses methods for using GIS to model watershed management alternatives.

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14. SUBJECT TERMS

Geographic Information Systems (GIS)	Watershed Management	Surface hydrology
GIS models	Soil erosion models	Hydrologic modeling
GIS procedures	Storm runoff models	User documentation
Cartographic models	Sediment yield models	GIS interfaces
Watershed Analysis	Revised Universal Soil Loss Equation (RUSLE)	Environmental models
Watershed Modeling	Modified Universal Soil Loss Equation (MUSLE)	
	Soil Conservation Service Curve Number method (SCSCN)	

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